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ABSTRACT

This manual was developed for use at workshops designed to upgrade the knowledge of experienced wastewater treatment plant operators. Each of the sixteen lessons has clearly stated behavioral objectives to tell the trainee what he should know or do after completing that topic. Areas covered in this manual include: sewage characteristics; collection, treatment, and sedimentation; aerobic and anaerobic digestion; sampling and interpretation; monitoring and control; and selected tests. (CS)

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PRIMARY TREATMENT AND SLUDGE DIGESTION WORKSHOP

First edition, September 1977

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Other manuals relating to the water and wastewater treatment processes published by the Training and Certification Section, Ministry of the Environment, include:

Basic Sewage Treatment Operation

Basic Water Treatment Operation

Surface Water Treatment Workshop

Activated Sludge Process Workshop

Preventive Maintenance Workshop

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INTRODUCTION

The *Primary Treatment and Sludge Digestion Workshop* manual has been prepared as a home study and reference manual for plant operators and as the text for the related workshop.

The principal objective of the Workshop is to upgrade the knowledge of experienced wastewater treatment plant operators. The lesson objectives are clearly indicated at the beginning of each topic and tell the operator what he must know or do after having covered the topic. Upon completion of the Workshop, the trainee is expected to attain a minimum level of competence of 70% for the course.

This is a working course in which each person is expected to take an active part in subject discussions. It includes considerable hands-on participation, in order to provide as much practical knowledge as possible of sludge digestion process control.

The Training and Certification Section wishes to acknowledge the assistance and contributions of the following in the preparation of the manual:

Ministry of the Environment:
   Pollution Control Branch
   Regional Operations
U.S.A. Environmental Protection Agency
Sacramento State College
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OBJECTIVES:

The trainee will be able to:

1. Describe, using a diagram, the typical sewage treatment plant.
2. Identify three sources of municipal sewage.
3. Discuss in general terms the physical, chemical and bacteriological characteristics of sewage.
4. Recall the approximate per cent BOD and suspended solids normally removed in the primary treatment plant.
5. Define terms commonly used in sewage treatment operations.
6. Discuss the effects a plant effluent could have on receiving waters if not adequately treated.

SEWAGE CHARACTERISTICS

GENERAL

The adequate treatment of sewage is one of the most important responsibilities of municipalities.

In the 19th Century, several large European cities built closed conduits or pipes for collecting human wastes when the use of streets as open sewers created intolerable living conditions. The discharge of these wastes to nearby rivers and streams soon produced obnoxious odours and ugly conditions.

At about the same time, epidemics were traced to water supplies originating from these rivers and streams. It was discovered that bacteria in the sewage caused diseases such as typhoid fever, dysentery, and cholera. The treatment of sewage thus became a necessity.

Sewage contains countless numbers of living organisms, most of them too small to be visible without the aid of a microscope. They are a natural living part of the organic matter found in sewage and they are important because they are one of the reasons for the success of our present treatment processes. Generally, the microscopic living organisms in sewage are *bacteria* and other more complex higher forms of organisms.

An intensive study of bacteria has shown that only a small number of them are disease carriers. These and other bacteria are destroyed in nature through the activities of higher forms of microbial life. Together, the organisms play a major role in *degrading* or *breaking down* organic matter (dead plants and animals and their wastes). By harnessing these organisms under ideal conditions, as in sewage treatment plants, the breaking down of organic wastes can be speeded up and controlled.

SOURCES OF SEWAGE

In nature, sewage is present as the waste by-product of human and animal life. Man has added to this the waste products of industrial and commercial activity. So the composition of sewage varies widely in both quantity and quality.

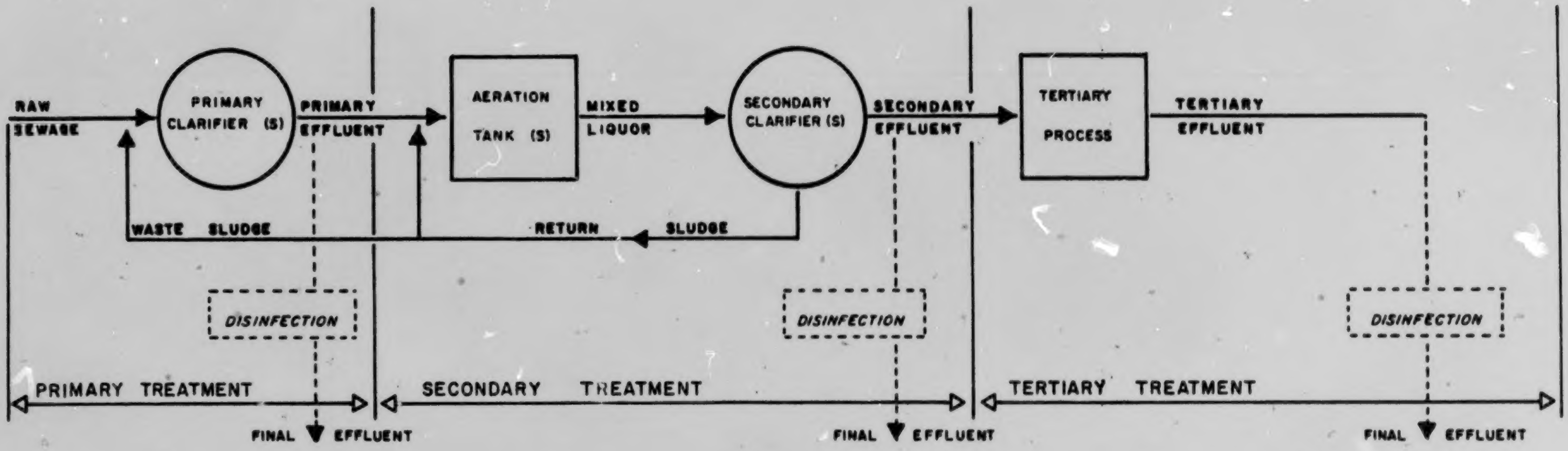
Domestic wastes are those that originate in the bathroom, the kitchen and the laundry room. Once these reach the municipal sewer and combine with any *industrial* and/or *commercial wastes*, they are called *sanitary* or *raw sewage.* Normal sanitary sewage is easily treated in a properly designed sewage treatment plant. Industrial and commercial wastes contained in the sanitary sewage may sometimes be unacceptable for treatment in a municipal sewage plant. In these cases, they must be pre-treated before they are discharged into the sewers.

Figure 1-1 is a schematic diagram of a typical conventional activated sludge plant. *Primary treatment* is used to remove settleable solids from the raw sewage entering the primary clarifiers. The liquid leaving these tanks, called *primary effluent*, may then be disinfected and discharged to a watercourse or directed to aeration tanks, the first stage of *secondary (biological) treatment.* The organic matter in the primary effluent serves as food for large numbers of organisms *(activated sludge)* in these tanks. With adequate oxygen, the organisms use the food for energy and reproduction.

The contents of the aeration tanks, called *mixed liquor*, then flow into secondary clarifiers where the organisms are allowed to settle and the clear liquid *(secondary effluent)* is either disinfected and discharged, or directed to a *tertiary treatment* process. The settled activated sludge is returned to the aeration tank for re-use, with waste sludge directed to the primary clarifiers. Tertiary treatment further removes solids and organic matter, using processes such as *lagooning*, *filtration*, or chemical treatment and *clarification*.

FIGURE Nº I-I

TYPICAL SEWAGE TREATMENT PLANT


RAW SEWAGE
PRIMARY CLARIFIER (S)
PRIMARY EFFLUENT
AERATION TANK (S)
MIXED LIQUOR
SECONDARY CLARIFIER (S)
SECONDARY EFFLUENT
TERTIARY PROCESS
TERTIARY EFFLUENT
WASTE SLUDGE
RETURN SLUDGE
DISINFECTION
DISINFECTION
DISINFECTION
PRIMARY TREATMENT
SECONDARY TREATMENT
TERTIARY TREATMENT
FINAL EFFLUENT
FINAL EFFLUENT
FINAL EFFLUENT

REMOVAL OF B.O.D. & S.S.	*B. O. D.*		*SUSPENDED SOLIDS (S.S.)*	
	% Removed	Effluent mg/l	% Removed	Effluent mg/l
PRIMARY PLANT	30 – 40	90 — 150	40 — 60	100 — 150
SECONDAY PLANT	95	15	90 — 95	15
TERTIARY PLANT	98	5	98	5

Before being discharged to any stream or waterway, the effluent is always treated with chlorine or some other disinfectant to destroy any remaining disease-causing bacteria. *Regardless of the amount of treatment given the sewage, the liquid leaving the plant is called the final or plant effluent.* Chemicals may be added to the sewage ahead of the primary clarifers, directly into the aeration tanks, or ahead of the tertiary process in order to remove phosphorus.

QUANTITY OF SEWAGE

In addition to carrying domestic, industrial and commercial wastes, the sanitary sewers may receive large quantities of water from rain and street washings. Water in the ground may also enter sewers through broken and poorly constructed sewer pipes and direct storm drain connections. This is called *infiltration.* Although older sewer systems may collect sanitary sewage and storm water in a single sewer, present policy requires the separate collection of each, since a treatment plant must be designed according to the total flows reaching it. It would be uneconomical to construct a large plant to treat immense quantities of very dilute sewage which only arrive during rainy periods.

The total quantity of sewage reaching the plant is called the *hydraulic load,* varying from hour to hour and day to day. Normally, daily flows will range between 70 and 130 percent of the water consumption. This percentage will rise if the entry of ground and surface water is a major factor. It will go down due to lawn watering, car washing, hydrant flushing and many other domestic and industrial uses from which the used water is not directed to the sanitary sewer system. An average municipality without large industrial sewage contributors will produce approximately 100 gallons of sewage per capita (person) per day (gpcd). Small rural municipalities and major cities will produce approximately 50 and 100 gpcd, respectively. *Solids account for less than 0.1 of 1 percent by weight of the total sewage flow. The remaining 99.9 percent is water, which carries the solids through the sewer pipes.*

QUALITY OF SEWAGE

A treatment plant removes undesirable materials from sewage, making it acceptable for discharge to lakes or streams. *In so doing, the bacteriological, physical, and chemical characteristics of the sewage are changed.* These changes can best be seen by comparing the characteristics of the raw sewage, primary effluent, secondary effluent, and final effluent of a treatment plant.

Bacteriological Characteristics

Fresh raw sewage may normally contain from 10 to 200 million bacteria per 100 millilitres. Some are harmful to humans and others are not. Complete secondary treatment reduces these numbers by 80 to 95 percent, with effluent chlorination increasing the percentage "kill" to 99.9 percent or better. The highest reductions are generally achieved only when the treatment plant is operating efficiently.

Physical Characteristics

The physical characteristics of sewage include *temperature, turbidity, colour* and *odour*. Table 1-1 compares the physical changes which take place through a typical treatment plant.

TABLE No. 1-1

FLOW	TEMPERATURE	TURBIDITY	COLOUR	ODOUR
Raw Sewage	generally warm	high in solids	milky-grey to black	musty to sulphurous
Primary Effluent	lower temperature	fine nonsettleable solids	greyish to colourless	musty to sulphurous
Secondary Effluent	lower temperature	no visible solids	clear colourless	fresh

The temperature of raw sewage will vary, depending on the source of water supply for the municipality. However, the resultant raw sewage is always somewhat warmer than the water supply. As the sewage passes through the treatment plant, the temperature decreases. The higher the sewage temperature, the faster the decomposition and the better the settleability.

Raw sewage is highly turbid, containing many different types of solids such as paper, rags, garbage, feces, sand and silt. Primary effluent will contain finely suspended and floating matter which can be removed by biological treatment, to produce a clear, colourless secondary effluent.

The normal milky-grey colour of raw sewage will not be evident if coloured industrial wastes or partially decomposed sewage are involved. Septic or partially decomposed sewage is dark, sometimes black in colour with a sulphurous odour. Normal sewage smells musty but not unpleasant. Primary effluent will be similar to raw sewage except that a large portion of the solids has been removed. The secondary effluent of a properly operated biological treatment plant will be clear and colourless with a fresh odour. Effluent chlorination does not affect temperature, turbidity or colour. It will, however, produce a fresh chlorine odour.

Chemical Characteristics

Chemically, sewage is composed of a great many inorganic and organic solids which are carried in water. The sewage may also contain dissolved gases and living organisms. Inorganic or *fixed* substances are inert and generally will not decay or burn. On the other hand, organic materials will decompose and are sometimes called *volatile matter* since they will burn when heated to high temperature.

Solids

Inorganic and organic substances which can be seen in the sewage are known as *suspended solids.* These are the solids which can be removed from the sewage by physical or mechanical means, such as sedimentation or filtration. Those that are not seen are classified as *dissolved solids. Total solids,* as the name implies, include all of the solids contained in sewage.

Inorganic solids consist of sand, silt, clay, the dissolved minerals and salts in community water supplies and any other inert matter contained in wastes discharged to the sewers. *Hard water produces a higher mineral content in the sewage.* Some of the more common minerals and salts found in sewage are sulphates, carbonates, bicarbonates and chlorides of calcium, magnesium, sodium, potassium and iron. These are beneficial to the organisms and not normally troublesome in a sewage treatment process.

Organic solids are generally of animal or vegetable origin. Some synthetic compounds, however, are also organic in nature. All organic matter consists of hydrogen, oxygen and carbon. These substances may be combined with inorganic nitrogen, sulphur or phosphorus. The principle groups formed are called proteins, carbohydrates and fats. These serve as food for bacteria and higher forms of organisms, resulting in decomposition or decay of the organic matter. Decomposition leads to the formation of carbon dioxide, nitrogenous compounds consisting of ammonia, nitrites and nitrates, and sulphurous substances such as hydrogen sulphide gas and various sulphate compounds. These waste products are in turn used by plant and animal life in their growth processes. The cycles of life, death and decay involve carbon, nitrogen and sulphur. These basic elements recycle in our environment where the products of death and decay become the foods for plant and animal life.

Quantities or concentrations of solids, whether inorganic or organic, will differ from hour to hour and from sewage plant to sewage plant. Typical concentrations of solids in a medium strength raw sewage are shown graphically in Figure 1-2. Sewage strength can be defined as the amount of organic material present in the sewage. The successful operation of a biological treatment plant depends, to a great extent, upon this sewage strength because it provides the food for the organisms.

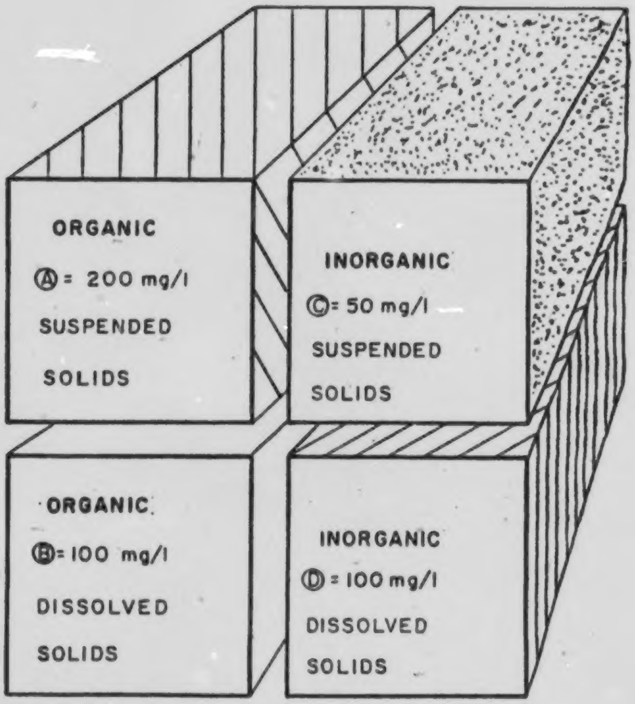
The total solids in a sewage consist of all suspended and dissolved inorganic and organic materials. From Figure 1-2 it can be seen that the concentration of total solids in medium strength sewage is approximately 450 mg/l. This consists of 300 mg/l organic matter in addition to 150 mg/l inorganic matter. The same total solids figure is arrived at by adding the suspended and dissolved solids (shown as 250 mg/l and 200 mg/l respectively).

When storm or ground water finds its way into the sewage, the relationships of these solids may change significantly. Similarly, industrial and commercial wastes may increase the solids content with definite variations in the strength of the sewage. Also, sewage will vary widely in both composition and volume from hour to hour, depending upon changes in community activities. Sewage is likely to be at its maximum strength and flow during the daytime and at its minimum during the night hours. On weekends and holidays, flows and strengths are often reduced due to slower communal activity. Therefore, data on sewage can never be applied equally to all sewages at all times.

A primary sewage treatment plant will normally reduce suspended solids by 40 to 60%. Complete secondary treatment generally will remove 90 to 95% of the suspended solids, producing a final effluent with suspended solids less than 15 mg/l.

FIGURE Nº 1-2

COMPOSITION OF SOLIDS IN A MEDIUM STRENGTH RAW SEWAGE


ORGANIC
Ⓐ = 200 mg/l
SUSPENDED
SOLIDS
INORGANIC
Ⓒ = 50 mg/l
SUSPENDED
SOLIDS
ORGANIC
Ⓑ = 100 mg/l
DISSOLVED
SOLIDS
INORGANIC
Ⓓ = 100 mg/l
DISSOLVED
SOLIDS

TOTAL SOLIDS = Ⓐ+Ⓑ+Ⓒ+Ⓓ = 200 + 100 + 50 + 100 = 450 mg/l

TOTAL ORGANIC SOLIDS = Ⓐ+Ⓑ = 200 + 100 = 300 mg/l

TOTAL INORGANIC SOLIDS = Ⓒ+Ⓓ = 50 + 100 mg/l

TOTAL SUSPENDED SOLIDS = Ⓐ+Ⓒ = 200 + 50 = 250 mg/l

TOTAL DISSOLVED SOLIDS = Ⓑ+Ⓓ = 100 + 100 = 200 mg/l

Total Solids

To determine the concentration of total solids in raw wastewater obtain one litre sample of wastewater entering the plant. Heat this sample enough to evaporate all the water and weigh the solid material left. The weight of this residue will represent the total solids which includes both dissolved and suspended solids. **Topic 11 discusses test procedures.**

Dissolved Solids

How much is dissolved and how much is suspended? To determine this, take an identical sample and filter it through a very fine mesh filter such as a membrane filter or fibre glass. The suspended solids will be caught on the filter and the dissolved solids will pass through with the water. Next, evaporate the water and weigh the residue to determine the weight of dissolved solids. *Subtract the weight of the dissolved solids from the weight of the total solids and the remaining weight will consist of the suspended solids.*

Suspended Solids

Suspended solids are composed of two parts: settleable and unsettleable. The difference between settleable and unsettleable solids depends on the size, shape, and weight per unit volume of suspended solids particles; larger size particles tend to settle more rapidly than smaller particles. Measuring the amount of settleable solids entering and leaving the settling tank allows the operator to calculate the efficiency of the clarifier for removing settleable solids. It is also important to know the amount of settleable solids in the raw wastewater for the purpose of proper operation of sludge pumps and sludge handling facilities. **Topic 10 discusses test procedures.**

It is possible to calculate the weight of non-settleable solids by subtracting the weight of dissolved solids and settleable solids from the weight of total solids.

Organic and Inorganic Solids

The strength of any wastewater is usually determined by the amount of organic material present in it. The organic solids, those suspended and dissolved, make up the greatest portion of the total solids in the raw waste. The successful operation of the biological treatment plant depends, to a great extent, on the organic characteristics of the raw waste. The standard test for determining the organic strength of wastewater is called the biological oxygen demand or BOD. This is simply a measure of oxygen used in decomposing organic matter. Normally, the test for BOD is carried out in a laboratory at a temperature of 20°C over a period of five days. Raw wastewater will normally have a BOD ranging of 150 mg/l to 250 mg/l. A primary sewage treatment plant will normally reduce the BOD by 30 to 40 per cent. Complete secondary treatment generally will remove up to 95% of BOD, producing a final effluent with a BOD less than 15 mg/l. This information is important for estimating solids handling capacity and for designing treatment process for removing the organic portion in waste.

Biochemical Oxygen Demand (BOD)

The standard for determining the organic strength of sewage is called the *Biochemical Oxygen Demand* or *BOD*. This is simply a measure of the oxygen used in decomposing organic matter. Normally, the test is carried out in the laboratory at a temperature of 20°C over a period of five days with the result being reported in ppm or mg/l 5-day BOD (BOD_5). **Topic 14 discusses test procedures.**

Raw sanitary sewage will normally have a BOD_5 ranging between 150 mg/l and 250 mg/l. Industrial and commercial wastes will affect this, however. *A primary sewage treatment plant will normally reduce BOD by 30-40%. Complete secondary treatment generally will remove 95% of the BOD, producing a final effluent with a BOD less than 15 mg/l.*

Dissolved Gases

Sewage contains small and varying concentrations of dissolved gases. Among the most important of these is *oxygen*, present in the original water supply and also dissolved from air in contact with the surface of flowing sewage. In addition to dissolved oxygen, sewage may contain other gases such as carbon dioxide, ammonia and hydrogen sulphide (the products of decomposition) as well as nitrogen dissolved from the atmosphere. These gases, although small in amount, can indicate the degree of sewage decomposition.

Nutrients

Nitrogen and *phosphorus* are two important nutrients in the operation of a sewage treatment plant and in the receiving watercourse. In the sewage plant they are essential for the growth of organisms involved in the decomposition of organic matter. Sanitary sewage normally contains an excess of both nitrogen and phosphorus. This excess, when discharged into the plant effluent, acts as an undesirable fertilizer, promoting the growth of algae in receiving waters.

Nitrogen is present in wastes in the form of ammonia, nitrite, nitrate, and organic nitrogen, each representing a different stage of waste decomposition. *Total phosphorus* is composed of a number of organic and inorganic compounds which may be present in a soluble or insoluble form. These compounds can be grouped into three categories: namely, orthophosphorus, organic phosphorus and polyphosphorus.

Table 1-2 summarizes the ranges of *typical* nitrogen and phosphorus analyses for a conventional secondary sewage treatment plant.

TABLE No. 1-2

FLOW	NITROGEN				PHOSPHORUS	
	Ammonia mg/l	Organic mg/l	Nitrite mg/l	Nitrate mg/l	Total mg/l	Soluble mg/l
Raw Sewage	15-50	25-85	less than 0.1	less than 0.5	6-12	4-6
Primary Effluent	15-50	25-85	less than 0.1	less than 0.5	4-8	4-6
Secondary Effluent	0-1	5-20	less than 5.0	greater than 10	3-6	2-5

In conventional sewage treatment very little nitrogen and phosphorus are removed, although they may change form chemically. Where high phosphorus removals were noted at activated sludge plants, the raw sewage usually contained aluminum or iron from industrial sources. By adding aluminum, iron or calcium compounds at the treatment plant, total phosphorus can be reduced to less than 1.0 mg/l in the final effluent.

THE EFFECTS OF WASTE DISCHARGES

When certain wastes, including domestic wastewater, do not receive adequate treatment, large amounts of solids may accumulate on the banks of the receiving waters, or they may settle to the bottom to form sludge deposits or float to the surface and form rafts of scum. This accumulation may result in oxygen depletion and also be the source of odours. Primary treatment units in the wastewater treatment plants are designed and operated to remove the sludge and scum before they reach the receiving waters, to prevent as much of this *"oxygen-demanding"* organic material as possible from entering the receiving water.

Although most streams and other surface waters contain less than 10 mg. of oxygen per litre of water most fish can thrive if there are least 5 mg. per litre and other stream conditions are favourable. However when organic waste is discharged to a stream, bacteria begins to feed on it and decompose or break down the complex substances in the waste into simple chemical compounds. In this process, the bacteria use dissolved oxygen from the water. Where waste flows are high, the population of bacteria may grow large enough to use the entire supply of oxygen from the streams faster than it can be replenished by natural diffusion from the atmosphere. When this happens fish and most other living things in the stream which require dissolved oxygen will die.

Another effect of oxygen depletion, in addition to the killing of fish and other aquatic life, is the problem of odours. When all the *dissolved oxygen* has been removed, then *anaerobic bacteria* begins to use the oxygen which is combined chemically with other elements in the form of chemical compounds, such as sulphate, which are also dissolved in water. When anaerobic bacteria removes the oxygen from sulphate compounds, hydrogen sulphide gas is released which has a rotten egg odour. In addition to being odorous, this gas also erodes concrete and can discolour and remove paint from plant structures and nearby buildings. Hydrogen sulphide may form explosive mixtures with air and is also capable of paralyzing the respiratory system.

Some wastes may adversely affect the clarity and colour of receiving waters making them unsitely and unpopular for recreation.

Many industrial wastes are highly acid or alkaline and either condition can interfer with aquatic life, domestic and other uses of water. Before wastes are discharged to a stream they should have a pH similar to that of the receiving water and preferably as near the neutral range as possible (pH7). Industrial waste discharges may contain toxic substances, such as heavy metals or cyanide, which may affect the use of the receiving water for domestic purposes or for aquatic life. Also, odour producing substances may reach levels in the receiving water which are readily detectable in drinking water or in flesh of the fish.

Conventional wastewater treatment plants do not remove a major portion of nitrogen and phosphorus nutrients therefore discharges from such plants contain nutrients capable of encouraging excess algae and plant growth in the receiving waters. These growths hamper domestic, industrial, and recreational uses. Therefore, wastewater treatment facilities located on certain streams or receiving water require installation of phosphorus removing equipment.

Human Health

To this point the physical or chemical effects that the wastewater discharge may have on the uses of water have been discussed. More important, however, may be the effect on human health through the spread of disease-producing bacteria and viruses. Many serious outbreaks of communicable disease have been traced direct to contamination of drinking water, or food supplies by body wastes from a human disease carrier. Although many of the pathogenic organisms are removed by natural die-off during the normal treatment process sufficient numbers could remain to cause a threat to any downstream use involving human contact or consumption. If these uses exist downstream, the treatment plant, without exception, must also include disinfection process of the effluent.

Proper chlorination of a well-treated waste will usually result in a complete kill of these pathogenic organisms. The operator must realize, however, that breakdown or malfunctioning of this equipment could result in the discharge of an effluent which contains pathogenic organisms.

SUBJECT: 2

SEWAGE TREATMENT OPERATIONS

TOPIC: 2

COLLECTION AND
PRE TREATMENT

OBJECTIVES:

The Trainee will be able to:

1. Name three types of sewers.
2. Discuss the effect on plant efficiency when wastewater takes a long time to reach the treatment plant.
3. Recall the purpose of pump stations.
4. Name the components usually making up the pretreatment process and state the purpose of each.
5. Recall the start-up and shutdown procedures for mechanical bar screens.
6. Describe four types of grit removal facilities.
7. Calculate velocity of flow and settling time in a grit chamber.
8. Recall the safety procedures when working on the pretreatment equipment.

COLLECTION
AND
PRELIMINARY TREATMENT

COMPONENTS OF A FACILITY

Facilities for handling wastewater are usually considered to have three major components or parts: collection, treatment, and disposal. For a municipality, these components make up the "sewerage" system or wastewater facility. Also, for an individual industry which handles its own wastewater, the same three components are necessary.

Collection of wastewater and transportation to a treatment plant is accomplished through a complex network of pipes and pumps of many sizes.

When wastewater enters a treatment plant it usually flows through a series of pretreatment processes; screening, shredding, and grit removal. These processes remove the course material from the wastewater. Flow measuring devices are usually installed after pretreatment processes to record the flow rates and the volume of wastewater treated by the plant.

Next, the wastewater will generally receive primary treatment. During primary treatment, some of the solid matter carried by the wastewater will settle out or flow to the water surface where it could be separated from the wastewater being treated.

Secondary treatment usually follows primary treatment and commonly consists of biological processes. This means that organisms living in the controlled environment of the processes are used to partially stabilize organic matter not removed by previous treatment processes and to convert it into a form which is easier to remove from the wastewater.

Waste material removed by the treatment processes goes to solid handling facilities and then to ultimate disposal. The objective of this workshop will be to discuss, in some detail, the treatment processes dealing with pretreatment, primary sedimentation and sludge digestion and handling.

COLLECTION OF WASTEWATER

Sanitary, Storm and Combined Sewers

In most municipalities the sanitary sewer coming into the treatment plant carries waste from household, commercial establishments and possibly from some industries. All storm runoff from streets and land, and roofs of buildings is collected separately in a storm sewer, which normally discharges to a watercourse without treatment. However, in some areas only one network of sewers has been laid out to pick up both sanitary waste and storm water in a combined sewer. Treatment plants, normally designed to handle the sanitary portion of the waste, sometimes must be bypassed during storms due to an inadequate capacity, allowing untreated waste to be discharged to the receiving waters. Also in certain areas, where the sanitary and storm sewers are separate, infiltration of groundwater or storm water into the sanitary sewers through breaks or open joints could cause high flow problems at the treatment plant. The plant operator is generally the first to know about the infiltration problems because of the unusually high flows he observes at the plant during periods of storm water runoff. Replacement or sealing of leaky sections of the sewer pipe is called for in these cases.

Sanitary sewers are normally placed at a slope sufficient to produce a flow velocity of approximately two feet per second. This velocity will usually prevent the deposition of solids that may clog the pipe or cause odours. Manholes are placed every three to five hundred feet to allow for inspection and cleaning of the sewer.

Pump Station

When low areas of land must be sewered or where pipe depths under the ground surface becomes excessive, pump stations are normally installed. These pump stations serve to lift the wastewater to a higher point from which it may again flow by gravity, or the wastewater may be pumped under pressure direct to the treatment plant. A large pump station located just ahead of the treatment plant may create problems by periodically sending large volumes of flow to the plant at one period of time, and virtually nothing the next. Such surges usually cause hydraulic shock loads through the plant, often resulting in carry-over of solids from one unit to another and into the effluent.

Major water-using industries which contribute waste to the collection system may affect the efficiency of a wastewater treatment plant, especially if there are periods during the day or during the year when these industrial waste flows are a major load on the plant. For instance, canneries are highly seasonal in their operations; therefore, it is possible to predict a time of the year to expect large flows from them. A knowledge of the location of the commercial and industrial discharges in the collection system may enable the operator to locate the source of a problem in the plant's influent, such as oil from a refinery or a gas station, etc.

The length of time required for waste to reach the plant may also affect treatment plant efficiency. Hydrogen sulphide gas may be released by anaerobic bacteria feeding on the waste if the flow time is quite long and the weather is hot; this may cause odour problems, damage concrete at the plant, and make the wastewater more difficult to treat. Wastewaters from isolated subdivisions located far away from the main collection network often have this aging problem.

PRELIMINARY TREATMENT (COMMONLY REFERRED TO AS PRE-TREATMENT)

General

An important part of the wastewater treatment plant is the equipment which is initially used to remove from the plant influent or reduce in size large solids, grease, scum and grit before any further treatment of sewage. Removal of these materials from sewage protects the pumps and other treatment devices from possible damage. Unless removed ahead of the plant these solids may obstruct pipelines, channels, ports, pumps, orifices and nozzles. They interfere with the moving parts such as chains, sprocket wheels, and shafts, or needlessly occupy space in the treatment structures. If the preliminary treatment devices do not function as intended, maintenance cost for pump repair, digester and clarifier clean outs, etc. will be greatly increased. The pretreatment facilities usually consist of the following:

1. screens (racks and bar screens)
2. shredding devices (comminutors, barminutors and rotogratorsl)
3. grit-removal units (grit channels, aerated grit-removal tanks, centrifuges, and detritors)
4. preaeration units.

SCREENS AND RACKS

Coarse screens are used principally to remove objects such as large pieces of wood, metal, bricks or floatables which may be washed into a combined sewer system. These screens protect pumps and grit chambers which may be installed ahead of the regular bar screen or mechanical shredders. These screens are constructed with evenly spaced rectangular or round bars approximately 2 inches apart and are installed at approximately 45 to 60 degree slope from the vertical and terminating at the horizontal platform. A rake is used to remove objects from this screen or rack.

Bar Screens

A bar screen is installed at nearly all plants as either the only screening unit or as a standby for shredding devices. The openings between the screen bars are usually between 3/4 to 2 inches.

Manually Cleaned Bar Screens

Manually cleaned bar screens, see Figure 2-1, require frequent attention. As the grease collects on the screen, it blocks the channel causing the wastewater to backup in the sewer. This, in turn, causes organic material to settle out; air depletion; and septic conditions develop in the wastewater producing hydrogen sulphide gas which is similar to rotten egg odour and is corrosive to concrete, metal and paint. If cleaning of the screens is infrequent, the surge of wastewater creates a sudden "shock load" on the plant, sometimes resulting in a poor effluent particularly in reduction of treatment efficiency throughout the various processes of the plant. Therefore for efficient operation the manually cleaned bar screens should be cleared regularly by using a proper rake. The screenings which are pulled up into the drain trough or the drain rake should be left there to drain dry before they are placed into collection containers for disposal.

Safety Precaution

Extreme caution should be exercised when raking the screen, footing may be poor due to water and grease

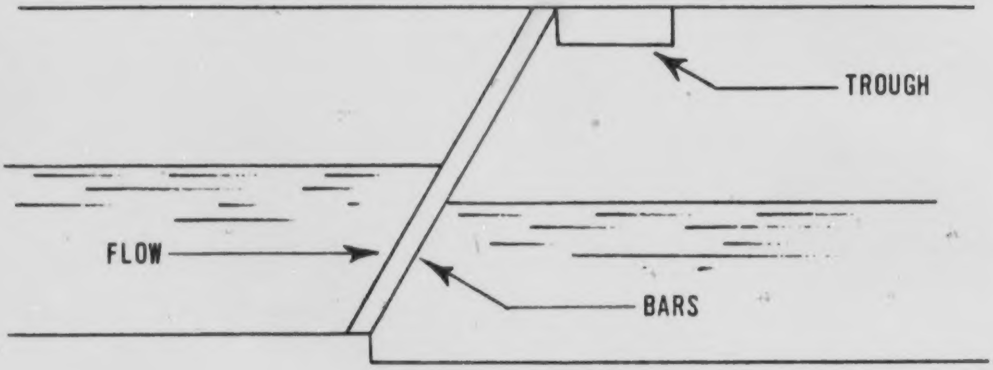

TROUGH
FLOW
BARS

Figure 2-1 Manually Cleaned Bar Screen

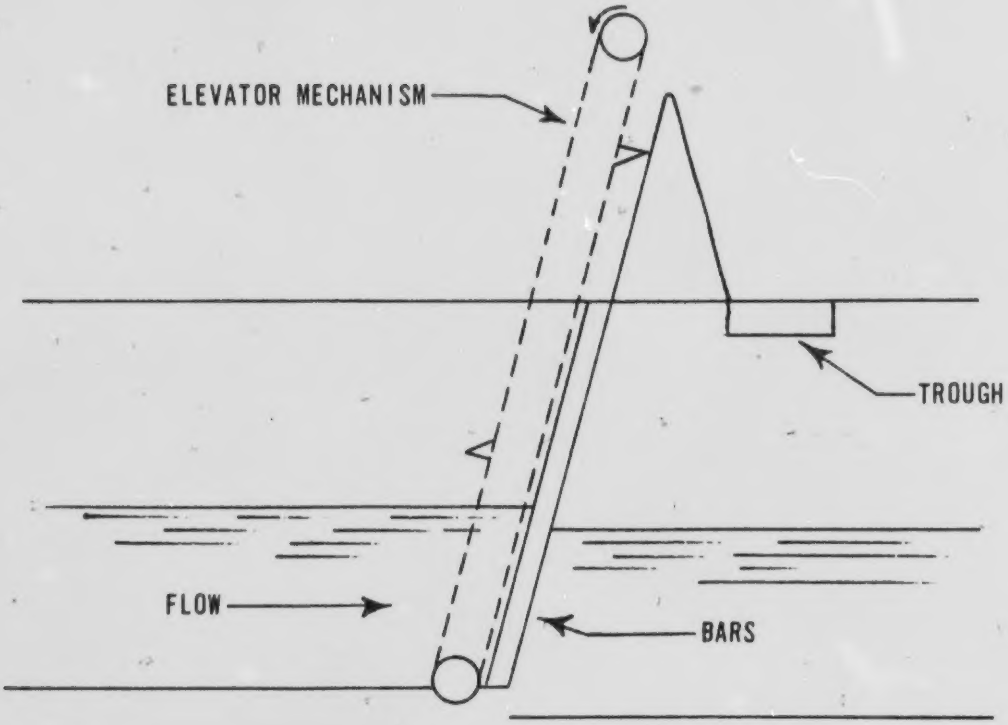

ELEVATOR MECHANISM
TROUGH
FLOW
BARS

Figure 2-2 Mechanically Cleaned Bar Screen

underfoot, lack of enough room to stand, location of receptacle for debris, etc. The operator should look this area over carefully to spot hazards and take corrective action like installation of grating, etc. Good housekeeping, a guard rail, a hanger or other storage for the rake, good footing, etc. will greatly reduce the possibility of injury.

Mechanically Cleaned Bar Screens (Figure 2-2)

The mechanically cleaned bar screen usually reduces the problem of wastewater backing up into the sewer and cuts down the manpower time involved in this part of the plant. There are various types of mechanisms in use, the more common being travelling rakes which bring the debris up out of the channel and into hoppers or other recepticles. The debris may also be deposited in a hammer-mill type of a shredder or grinder for size reduction. Following the shredding the solids can be returned to the sewage flow or disposed of separately. Occasionally there will be something which the mechanical equipment will not be able to remove. Therefore, regular checks should be made to determine if some material is stuck on the screen or at the base of it, either by diverting the flow to another channel or by raking across the screen with a hand rake. These units should be well lubricated and adjusted periodically, a few minutes spent in proper maintenance procedures can save hours or days of trouble and help to keep the plant operating efficiently.

Safety Precaution

Always shut off the unit first. Never reach into operating range of the machinery while it is running. Slow-moving equipment is especially hazardous because it moves slowly, it does not appear to be dangerous. However, most geared-down machinery is so powerful it can crush almost any obstruction. THE HUMAN HAND, for instance offers little resistance to this type of equipment.

Start-Up Procedures For Mechanical Bar Screens

1. Inspect the bar screen and the channel of the unit prior to start-up as follows: a) examine the motor, air reducer, sprockets, chains, rakes and rake wiper to verify that they are free of tools and debris and are properly positioned for normal operation; b) inspect the speed reducer for sufficient amount of oil and lubricate all necessary moving parts; c) check the channel to make certain it is free of tools, ladders and debris; d) make certain that all personnel are clear of the units and are aware of the start-up.

2. Immediately after starting the bar screens do the following checks: a) make certain that the motor or the mechanism is holding in proper direction; b) check to make certain the entire assembly of the raking mechanism, particularly those parts of the unit that normally run under water, are moving properly and produce no unusual sound; c) stop the unit after being satisfied with its start-up.

3. Put the bar screen on line by doing the following:

   a) Close the drain valve by turning the handle clock-wise.

   b) Equalize the waterhead on the isolation gates by opening the valve and allowing the water level to become the same on both sides of the gates.

   c) Pull the isolation gates out of the channel and hose them down and store them in the storage pit.

   d) Restart the bar screen and observe its operation for approximately 5-minute period or two complete cycles, and if everything is functioning properly turn the motor-control switch to automatic position.

4. Put the shredder on line by doing the following:

   a) Start the grinder and verify by observation that the motor is rotating in proper direction and the grinder operates smoothly and produces no unusual sounds.

   b) Observe the grinder discharge to make certain that the flow is normal and that the screenings are being properly shredded.

SHUTDOWN PROCEDURE FOR MECHANICAL SCREENS

1. Put the alternate mechanical screen into service.

2. Install the upstream and downstream isolation gates.

3. Turn the bar screen motor switch from automatic to hand position. WHY? To assure the removal of all collected material from the screen and the rakes while draining the channel.

4. Remove the over-gratings from the channel and put up the barricades and/or ropes around the channel.

5. Open the channel drain.

6. As the water level in the channel recedes, use high pressure hose to hose down the channel walls, floor and screen equipment. WHY? If solids are allowed to air dry, they will adhere to the walls and the equipment and cause odour problems; also after having dried on to the walls or the equipment the solids are difficult to remove.

7. Turn the bar screen motor control-switch to the off position and insert the LOCKOUT stop-switch bar.

8. Turn the grinder motor-control switch off, and lock the breaker handle in the open position, and attach LOCKOUT tag. WHY? To prevent start up of the equipment by another person which may cause damage to the equipment or injury to persons working on the equipment.

MAJOR SAFETY FACTORS IN HANDLING OF MECHANICAL SCREENS

1. Put up barricades or ropes around the opening when gratings are removed.

2. Enter the channel using a sound ladder and properly placed on the bottom. The ladder should be securely fastened at the top to prevent it from slipping sideways. Channels which are more than 5 feet in depth should require the wearing of safety harness and there should be two men on this job. Caution should be practiced as the floors are usually very slippery due to accumulation of greasy materials and slime.

3. Make certain that all the motors associated with the screening device are turned off and are LOCKED OUT with LOCKOUT tags on the power box.

4. Clean up all spilled lubricants or other greasy material that may be found on the floor of the channel.

6. Brace the sprockets as indicated in the Operational Manual. Because of tension in the chains, sprockets may turn by themselves resulting in injury to the operator. During the adjustment of the rake wipers make certain that the wipers are resting on their proper stops before performing any work on the unit. Should the wiper slip and fall it could crush the operator.

8. Do not allow process water to splash on the face or any exposed skin, because there is always a danger of possible infection by disease causing organisms or injury from hazardous chemicals present in the wastewater.

9. When working on grinder or screening equipment in deep channel it is advisable to close and tag all the inlets to the channel before starting work on the units. Should an inlet valve be opened by accident, major flooding could occur causing injury or possibly drowning of the operator.

GRIT REMOVAL

Grit, in the influent received at the plant, comprises of sand, dust, stones, cinders and other heavy and organic material. Grit removal usually follows or is part of the screening process. Most sewer pipes are laid at a slope which is deep enough to keep the wastewater flowing at the rate of 2 feet/second, at this rate of flow usually the grit is kept in the liquid suspension until it reaches the plant. If the velocity of flow is reduced to below that of 1.5 ft./sec. some of the heavier particles suspended in sewage will settle out. Should the velocity for any reason be reduced to 1 ft./sec., materials such as sand, eggshell and cinders will settle out while only the lighter organic material will remain in suspension. In theory, if efficient removal is practiced, grit should contain little organic material and possibly could be disposed of as fill in the vicinity of the plant. However, in practice this is not always possible usually the grit removed by the grit removal facility will still contain a fair amount of organic material. Therefore, this type of grit should be disposed of at a local sanitary landfill. Grit removal units are usually installed after screening equipment and the primary purpose of this process is to protect the mechanical equipment from abrasion, to avoid pipe clogging, to reduce the sedimentation load on the primary clarifiers and to prevent problems with mixing, recirculating, and retention time of sludge in settling tanks and digesters.

DESCRIPTION OF THE PROCESS

Types of Facilities

Grit removal facilities are built in a variety of forms and shapes. They are as follows:

a) Grit Channels (Figure 2-3)
b) Aerated Grit Chambers (Figure 2-4)
c) Detritus Tank
d) Centrifugal Separators

GRIT CHAMBERS

The simplest means of removing grit from the wastewater flow is to pass it through channels or tanks which allow the velocity of the flow to be reduced to one foot per second. The objective is to allow the grit to settle to the bottom, while keeping the lighter organic solids moving along to the next treatment unit.

The grit chamber is usually an narrow channel with a square or circular tank designed to allow the required reduction in the velocity of flow. The settled grit may be removed from the grit chamber either by hand or mechanically and stored in a appropriate container until disposed of in an approved manner. Hand cleaned grit chambers are common to small plants and usually consist of two parallel channels with velocity controls. Some devices used to control the velocity are Parshall flumes, Parabolic flumes, or Proportional weirs. With multiple channel installations, the operator may vary the number of channels in service at any time to maintain a flow velocity of approximately 1 ft./sec. in the grit chambers. The other method in controlling the velocity of flow involves the use of proportional weirs at the outlet of the chamber for automatic regulations of the flow. The proportional weir will tend to decrease the velocity in the grit chamber when the flow increases because the excess area will decrease, thus increasing the depth of the water flow in the channel itself. If the operator wishes to increase the velocity of the flow in the grit chamber, he could use a proportional

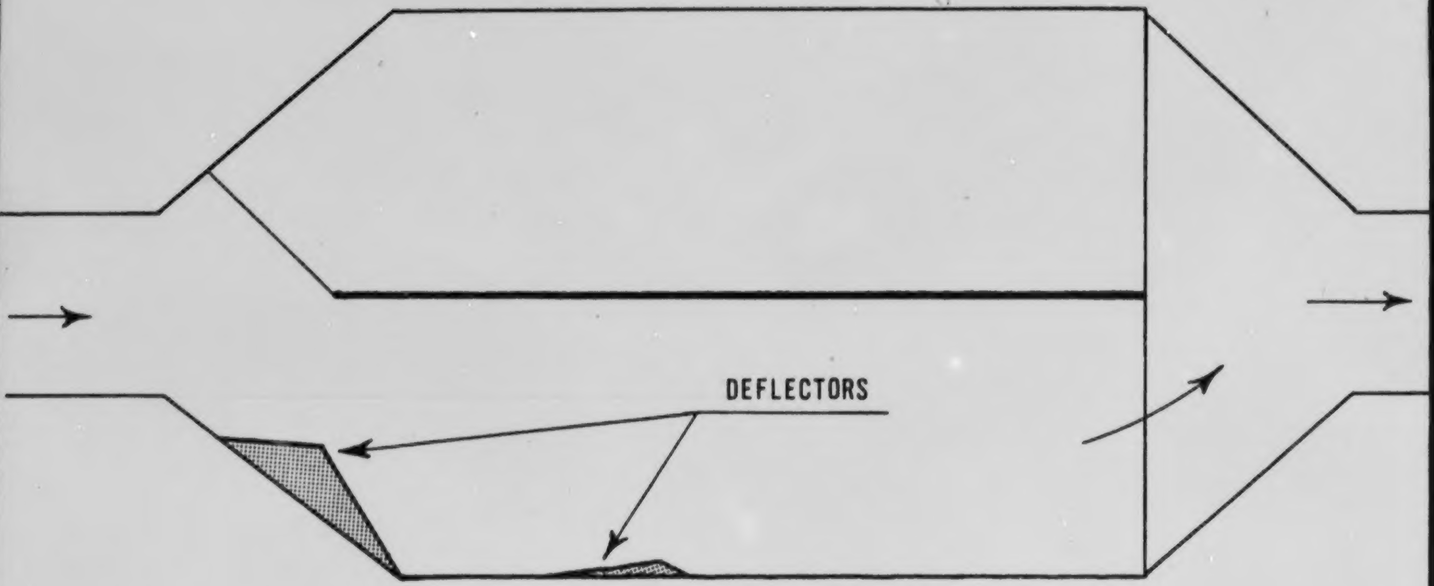

DEFLECTORS

Figure 2-3 Grit Chamber with Deflectors.

weir and turn it over so that the access area increases as the flow to the plant increases. This would tend to keep the depth of the water flow in the channel low and cause higher velocities. Also, the area with a variable height at the outlet of the grit chamber can be used instead of the proportional weir to regulate the velocity.

The velocity can also be regulated by the shape of the grit chamber instead of placing devices at the outlet. Some grit chambers have a cross-sectional shape similar to a proportional weir. The operator may also regulate the velocity of the grit chamber by using boards to change the cross-sectional shape, but he should seriously consider any maintenance or operational problems that may develop when trying to keep the grit chamber clean. A simple method of estimating the velocity of flow is to place a stick in the channel and time its travel for a measured distance. This method of measurement may be calculated as follows:

Velocity, feet per secpmd is distance travelled in feet/second
this set over time, seconds

EXAMPLE: X travels 25 feet in 20 seconds.

SOLUTION: velocity, feet/second = distance in feet over time in seconds

25 feet over 25 seconds = 1.25 feet/second

The actual velocity will probably be slightly higher than the estimated calculations but it is a very quick way to check the grit chamber velocity.

A more accurate method for determining the average velocity in the grit chamber is to find the cross-sectional area of the wastewater flowing in the grit chamber and the quantity of flow (from the flow meter) as calculated in the following example.

Assume that the grit chamber is 2 feet wide. The wastewater flowing at a depth of 1 ft., and the flow meter registered at a flow of 1 mgd. The cross-sectional area flow is (depth, in feet X width in feet = 1 ft. X 2 ft. X 2 sq. ft.). The flow must be converted into cubic measure, thus, from calculations shown below. 1 mgd = 1.55 cu.ft./sec.

$$1\ \text{MGD(US)} \quad \frac{1{,}000{,}000}{7.5 \times 24 \times 60\ \text{min/hr} \times 60\ \text{sec/min}}$$

$$= 1.55\ \text{cu.ft./sec.}$$

Using this factor

$$\text{Average Velocity} = \frac{\text{Flow Rate, cu.ft./sec}}{\text{Area, sq. ft.}}$$

$$= \frac{1.55\ \text{cu.ft./sec.}}{2\ \text{sq. ft.}}$$

$$= 0.77\ \text{ft/sec.}$$

To obtain this answer convert the flow from mgd. to cu. ft./sec. and divide the flow (1.55 cu.ft./sec.) by the cross-sectional area of the wastewater in the channel. After the velocity has been checked, the next thing to do is to determine if the length of the channel is appropriate for the flow condition. All particles have a different rate of travelling, based on the size and weight. Most grit chambers are designed to remove sand particles which are 0.2 ml. in size and all other heavier material. It has been established through a series of experiments that this size of particle (0.2 ml) will settle downward at about 0.075 ft./sec. This means that if the wastewater is flowing in the channel at a depth of 1 ft. and a velocity of 1 ft./sec., it would travel a distance of about 13.3 ft. in about 13.3 sec. before the particle reached the bottom. Therefore, if the waste were flowing at a depth of 3 ft. in the channel, it would take 13.3 sec./ft. X 3 ft. which would = 239.9 sec. or a distance of 39.9 ft. before sand reached the bottom therefore, the required length of any grit chamber be checked by using the following formula:

$$\begin{aligned}\text{Settling Time, sec.} &= \frac{\text{Depth in ft.}}{\text{Settling Rate in ft./sec.}}\\ &= \frac{1\text{ ft.}}{0.075\text{ ft./sec.}}\\ &= 13.3\text{ seconds to settle.}\end{aligned}$$

In case of dead spots in the grit chamber (where organic materials settle out and become septic, a deflector installed at one side of the channel may cure the problem. However, some care should be exercised to make sure that the installation of the deflector does not create a new dead spot in the channel. Also, certain trouble spots could be filled in with concrete. See Page 2-14.

AERATED GRIT CHAMBERS

An aerated grit chamber is actually a deep tank with a sloping bottom and a hopper or trough at the lower end (see **Figure 2-4**). The air is injected into the tank along the wall above the trough. The rolling action of the water in the tank moves the grit along the bottom to the grit hopper, while the lighter organic particles which are suspended in the liquid by the rolling motion are discharged at the surface of the tank. The grit collected in the tank bottom is normally removed by a clam shell bucket or airlift unit.

Aerated grit chambers most frequently found in larger plants particularly in activated sludge process systems where there is a readily available air supply. The advantage of having an aerated grit chamber in certain instances helps freshen up the incoming wastewater thus making later processes more effective.

DETRITUS TANK

Short-period sedimentation in a tank that operates at substantially constant levels produces a mixture of grit and organic solids called Detritus. The lighter organic

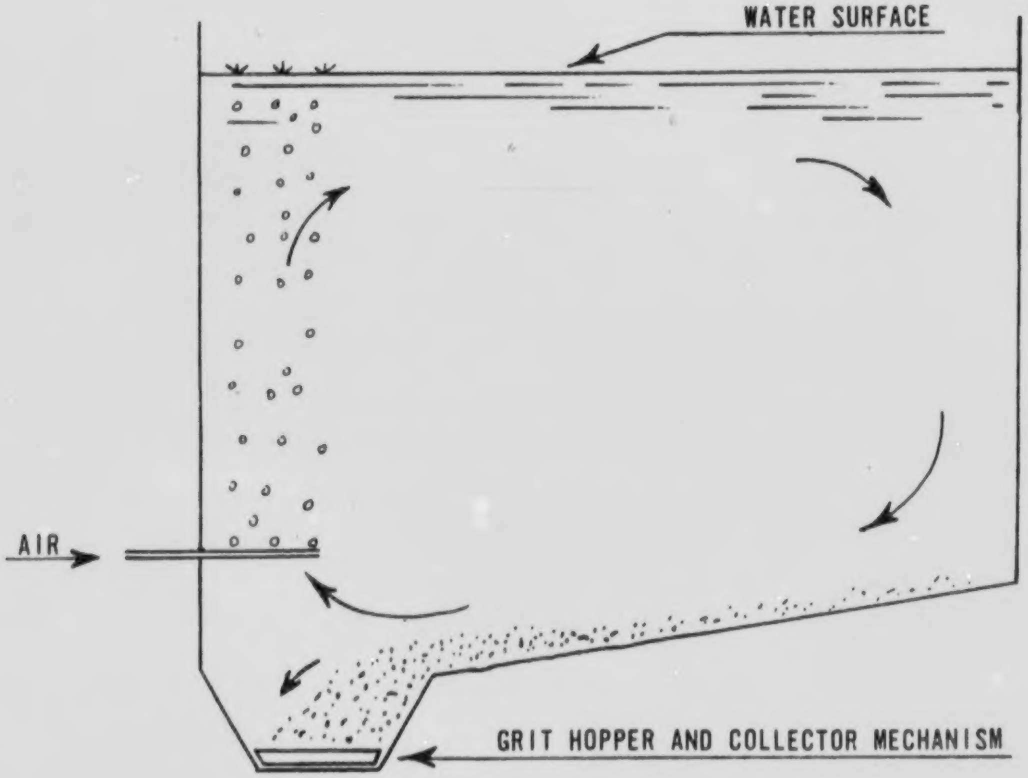

WATER SURFACE
AIR
GRIT HOPPER AND COLLECTOR MECHANISM

Figure 2-4 Aerated Grit Chamber

solids are subsequently removed or washed out of the mixture. Organic matter may be separated from the grit by blowing air through or washing the detritus to return the organic matter to the flow.

Several manufacturers specializing in sewage treatment equipment have perfected this type of process. For example, one such unit not only removes the grit but also washes it.

The grit-collecting mechanism is installed in a square, shallow, concrete tank with built-in sloping corners. The sewage enters in one side of the tank through adjustable vertical gates which are set to provide a uniform instant velocity across the entire wiedth of the unit. Then the sewage flows in straight lines across the tank and overflows at a weir constructed along the outlet side of the tank.

The collecting mechanism consists of two structural field arms, attached to a vertical shaft and fitted with outward raking blades with scoops on the ends. As the rakes revolve, settled grit is ploughed outward to the radius were the end scoops collect and discharge it to a hopper at one side of the tank.

CENTRIFUGAL SEPARATORS

Another method by which grit can be removed from wastewater is by use of centrifugal separators. These units are usually in the form of a liquid cyclone. Wastewater is introduced tangentially into the rendrical conical housing. The grit consisting of heavier, larger particles thrown to the outside wall and is collected for disposal. The wastewater leaves the centre of the housing as overflow.

CLEANING GRIT CHAMBERS

Cleaning grit chambers manually, can be quite hazardous. The operator should take precautions against slipping and backstrain. He should be aware and cautious of dangerous gases when working in covered or deep grit chambers. There are a number of types of mechanical grit collector mechanisms. The common ones are chain-driven **scrapers called Flites**, that are moved slowly along the bottom and up an incline out of the water to a hopper, or along the bottom to an underwater trough where a screw conveyor lifts the grit to a storage hopper or a truck. Some designs use conveyor belts with buckets attached. When starting or shutting down this equipment standard plant operational procedures should be followed particularly with regard to safety precautions. Also, while carrying out cleaning operations of any grit chamber the operator should prevent the splashing of sewage into the eyes or face. Heterogenetic organisms that abound in wastewater could cause infection to the operator or he may contact such water-borne diseases as typhoid fever, hepatitis or even tetanus.

SHREDDING DEVICES (Figures 2-5, 2-6)

In the wastewater treatment process shredding devices are often referred to as comminutors or barminutors. Comminutors and barminutors are devices which act as both cutters and screens. Their purpose is to shred (comminute) these solids and leave them in the wastewater. This process overcomes the problem of the screenings disposal. As with screens, they are mounted in a channel, and the wastewater flows through them. The rags, pieces of wood, and other small objects are shredded by the cutter's (teeth) until they can pass through the screen openings. Larger pieces of wood, plastics or other hard materials are rejected and must be removed from the channel by hand. Most of these units have a shallow pit in front of them to catch the rock and scraps of metal. The flow through the shredding device should be shut off periodically and the collected debris removed from the traps. The frequency of checking the traps can be determined from experience. This unit should be checked at least once per shift. The shredding device called 'comminutor' consists of a rotating drum with slots for the wastewater to pass through (see diagram below). Rotating teeth are mounted in rows on the drum. The teeth pass through the cutter bars or what is commonly referred to as the 'comb' with very small clearances so that a shearing action is obtained. Wastewater passes into the vertically-mounted drum through the slot in the drum and flows out at the bottom. A rubber seal, held in place by a bolted-down ring, prevents leakage under the drum. This seal should be checked every time whenever the rock and scrap metal trap is being cleaned of the collected debris.

Another variation of the shredding device is the barminutor (see page 2-23). This unit consists of a bar screen made of U-shaped bars and a rotating drum with teeth and shear bars. The rotating drum travels up and down the bar screen. Careful attention must be given to maintaining the oil level in these machines; otherwise water may get

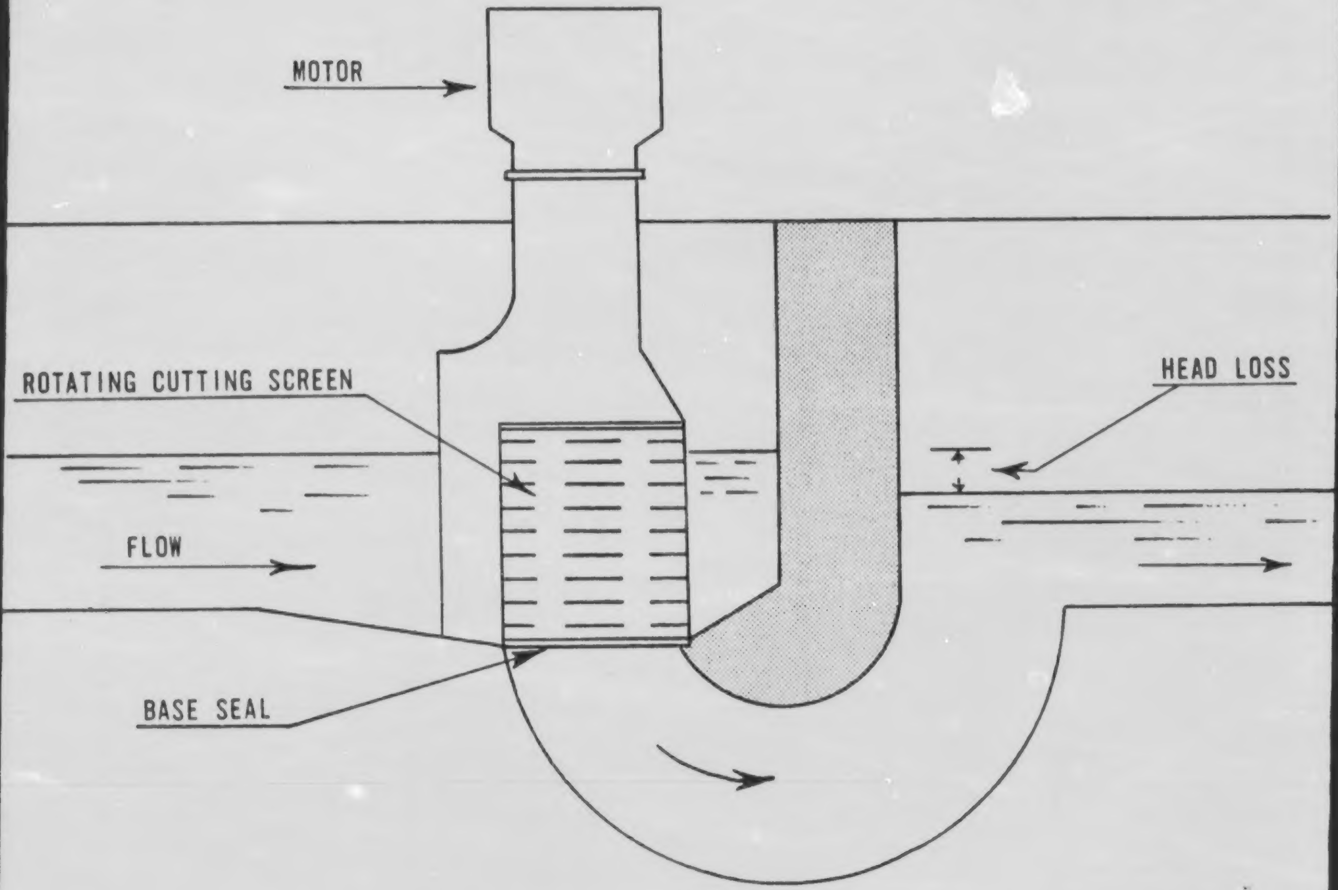

MOTOR
ROTATING CUTTING SCREEN
HEAD LOSS
FLOW
BASE SEAL

Figure 2-5 Comminutor

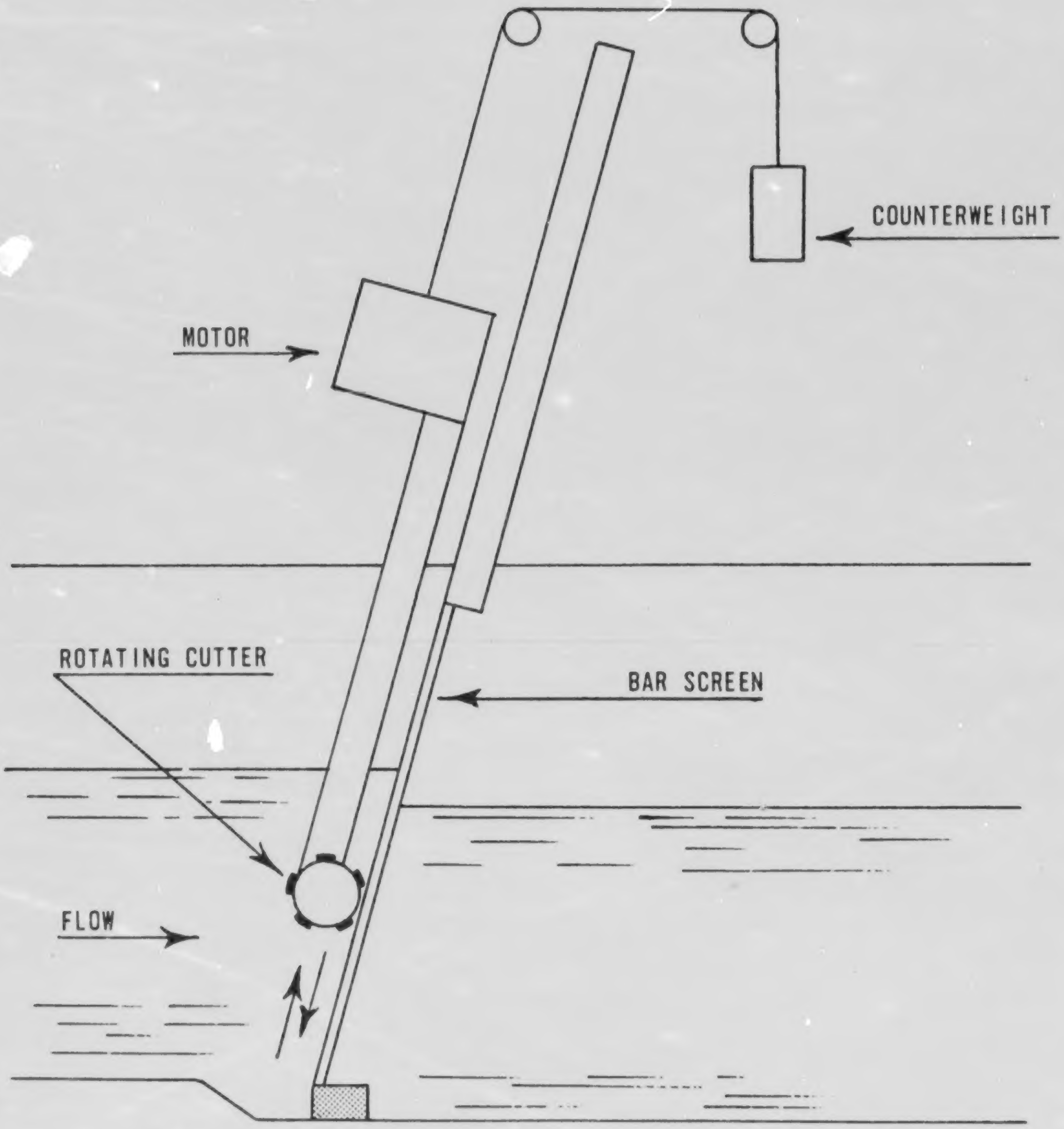

COUNTERWEIGHT
MOTOR
ROTATING CUTTER
BAR SCREEN
FLOW

Figure 2-6 Barminutor

into the bearings. For proper maintenance of this equipment the operator should consult the manufacturers instruction manual for detailed procedures.

Some comminutors are equipped with a Mercury Seal (Figure 2-7), to keep the water out of the bearings. This is because these units are designed so that, at the rate of capacity, the top of the drum is normally operating under several inches of water. The mercury seal should be checked at least annually, more ideally after a particularly heavy flow. For proper maintenance of this seal the following procedure should be followed: drain the mercury from the seal compartment; weigh it (the amount of mercury required will be specified by weight in the Maintenance Manual); and if the mercury is dirty, strain it through some heavy material, such as denim or chamois, before putting it back in the comminutor. During straining, the mercury may have to be squeezed through the cloth or, if laboratory equipment is available, a suction flask should be used. If some mercury was lost during the straining operation more mercury should be added to the unit to make certain that it has been filled to the required level in the comminutor.

Mercury is poisonous. Breathing the fumes can be fatal or may result in loss of hair and teeth. Wash up thoroughly after handling it. Remove gold rings, etc., from your hands first, as they may end up coated with mercury. If the ring happen to get coated, it will have to be heated to burn off the mercury. If one must handle or work with mercury, be certain to work over a large tray in order to catch any spills. Plenty of fresh-air ventilation is an absolute must in the working area when straining the mercury.

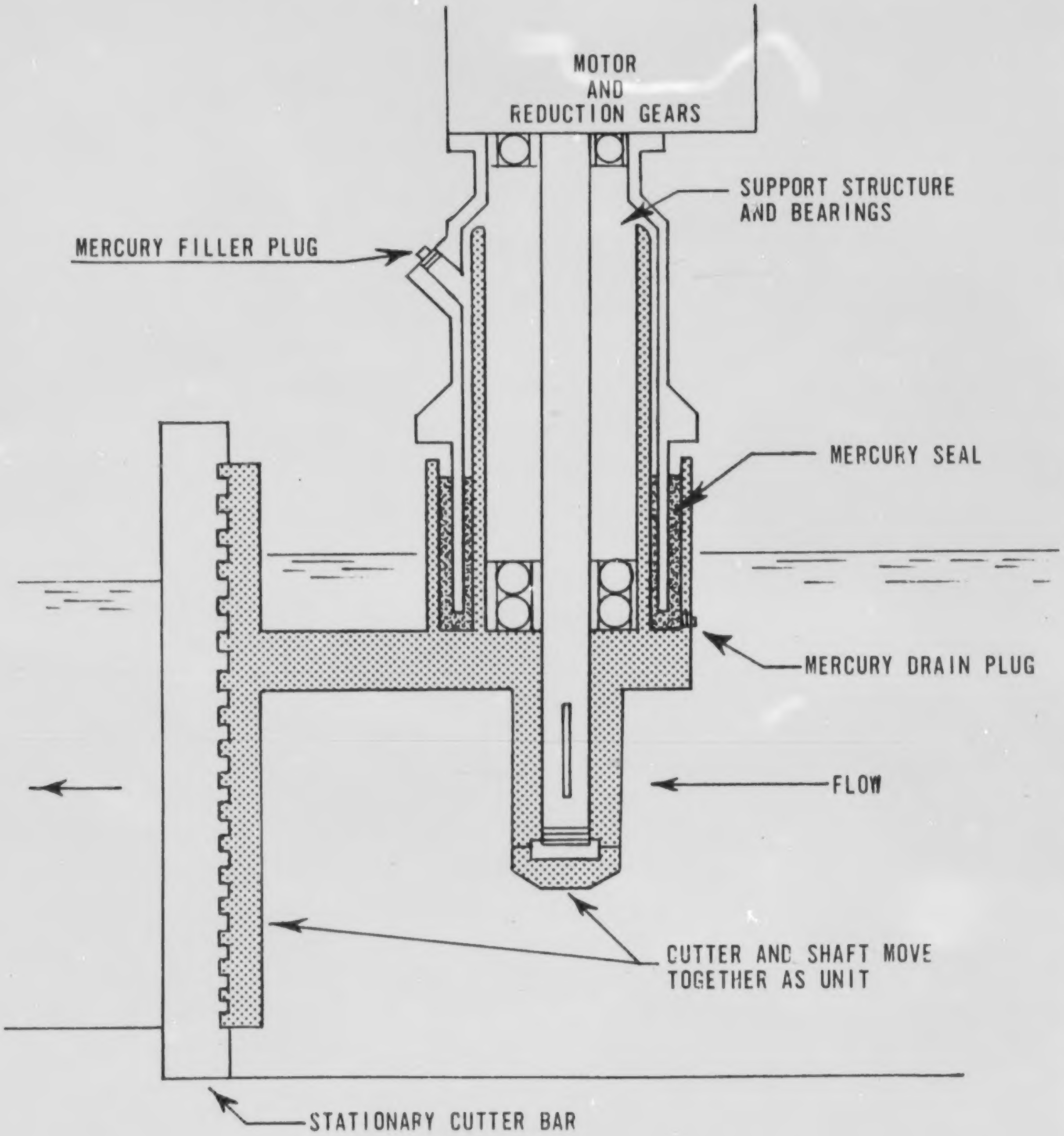

MOTOR
AND
REDUCTION GEARS
SUPPORT STRUCTURE AND BEARINGS
MERCURY FILLER PLUG
MERCURY SEAL
MERCURY DRAIN PLUG
FLOW
CUTTER AND SHAFT MOVE TOGETHER AS UNIT
STATIONARY CUTTER BAR

Figure 2-7 Mercury Seal in Comminutor

SUBJECT: 3

SEWAGE TREATMENT OPERATIONS

TOPIC: 3

PRIMARY SEDIMENTATION

OBJECTIVES:

The Trainee will be able to:

1. Name 4 common sedimentation and flotation units.
2. Name and discuss the factors affecting sedimentation.
3. Calculate detention time and weir overflow rate.
4. Discuss the methods of grease removal.

PRIMARY SEDIMENTATION

GENERAL

Solids, once suspended in the wastewater, are carried forward as a result of velocity of flow and mixing action of the liquid. When the velocity of flow and the mixing action is sufficiently reduced these solid materials will begin to settle and the floating materials will rise to the surface of the liquid. Therefore, in waste treatment, process sedimentation and flotation units are designed to remove physically those solids which will settle easily to the bottom or float easily to the top. Sedimentation is the principle basis of design in such units and will be discussed in more detail later in this section. Flotation of fats, oils, hair, and other floating material, which collectively are called greases or scum is also a very important part of the treatment process in protection of the aesthetics and the receiving waters.

In the waste-treatment process the sedimentation and flotation units commonly found are: (1) primary clarifiers; (2) secondary clarifiers; (3) flotation units; and (4) Imhoff tanks.

FACTORS INFLUENCING SEDIMENTATION

The most important function of the primary clarifier is to remove as much settleable and floatable material as possible. Organic settleable solids removal is very important because it causes a high demand for oxygen (BOD) in receiving water or subsequent biological treatment units in the treatment facility.

The sedimentation of solids in the primary clarifiers are most commonly affected by the following factors:

1. Physical Characteristics of the Waste
2. Temperature of the Incoming Waste
3. Detention Time in the Tank
4. Weir Overflow Rate
5. Short Circuiting of Flow Through the Tank

Physical Characteristics

The effectiveness with which the solids will settle out in wastewater is by and large affected by the following two parameters: (a) the strength and the freshness of the wastewater; and (b) the density, shape and size of the particles.

Also, under normal circumstances strong wastewater usually settles out more rapidly than weak wastewater. However, stale wastewater will settle out less readily than fresh wastewater because the particle sizes are reduced by biological degradation and also the particles tend to be buoyed up by the gases produced in stale wastewater.

The rate of downward travel (settling) of a particle depends on the weight of the particle in relation to the weight of an equal volume of water (specific gravity), the particle size and shape, and the temperature of the liquid. A dense particle settles out more rapidly than a light one; a particle with a large surface area, in relation to its weight, settles slowly; and one with irregular shapes has greater frictional drag and settles more slowly than a particle with a regular shape. However, it is important for the operator to know that organic settleable solids are seldom more than one to five per cent heavier than water; and therefore, their settling rates are rather slow.

Temperature

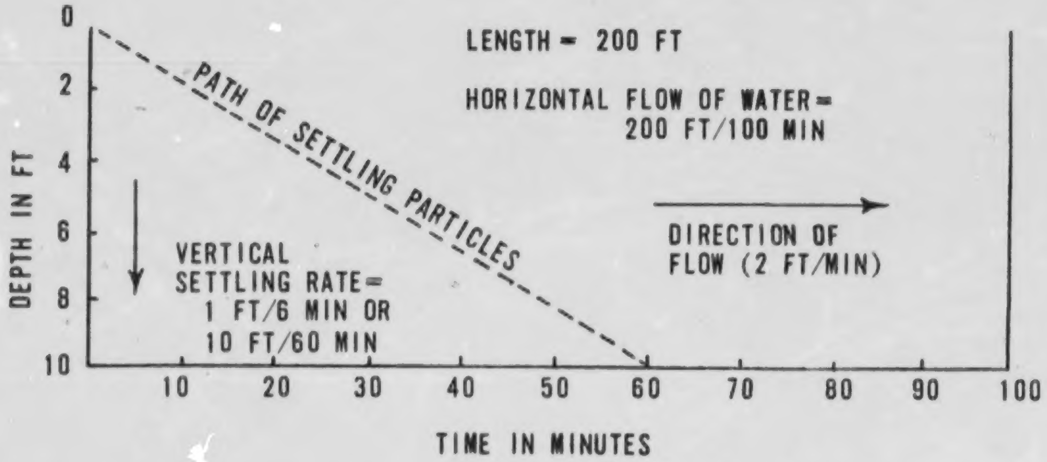
In general, as the water temperature increases, settling rate of particles in the wastewater increases; and as the temperature decreases, so does the settling rate of particles in the liquid. The reason for this is that the molecules of water react to temperature changes. They are closer together when the liquid temperature is lower; thus density increases and the water becomes heavier per given volume because there is more of it in the same space. As the water becomes more dense, the density difference between water and the solid waste particles becomes less; and therefore the particles tend to settle out slower.

To illustrate the meaning of density for the purpose of this particular topic, density means the weight per unit volume of any substance. The density of water at 4° C. is 1.0 g/ml or about 62.4 lb/cu.ft. If one cubic centimeter of substance, such as iron, weighs more than 1.0 g , it will sink or settle out when placed in the water. On the other hand oil which has a lower density or weighs less than water, it will rise to the top and float. Wastewater sludge density is normally expressed in g/ml.

Detention Time

Detention time is the period required for the wastewater to flow through the clarifier at a given rate of flow. This detention period should only be sufficient or long enough to allow practically complete removal of settleable solids. Detention of wastewater, in the primary clarifiers, for a period longer than necessary does not materially improve removal of solids and may actually be harmful by allowing the wastewater to become septic. Therefore, the relationship of detention time to settling rate of the particles is of great importance. This is why most of the clarifiers are designed for about 2 to 4 hours of detention time.

In a sedimentation tank if the the horizontal velocity of the liquid is slowed to a rate of 1.0 to 2.0 feet of travel per minute most particles with a specific gravity of 1.05 (5% heavier than water) will settle to the bottom of the tank. If we recall the horizontal velocity in the grit chamber is normally 1 ft. per second, whereby in the settling tank the required horizontal velocity of the liquid flow is called for 1 to 2 feet per minute. To better understand the difference in the specific gravity of water to that of settleable solids one should know that the specific gravity of water is 1.000 at 4 degrees C. or 39 degrees F.; and at this temperature the water weighs ten pounds per gallon. Wastewater solids with a specific gravity of 1.05 will weigh 10.50 lb/gal. The relationship of the particle settling rate to liquid velocity may be explained very simply by using the following sketch.



Let us suppose that the horizontal liquid velocity is at the rate of 2 ft/min. and the tank is 200 ft. long. It will take 100 minutes for the liquid to travel through the tank. If the particle, during its diagonal course of travel, settles vertically towards the bottom of the tank at a rate of 1 ft. in 6 min., it will rest on the floor of the tank in 60 min. if the tank is 10 ft. deep. If the particle settles at the rate of 10 ft. in 60 min., it should settle in the first 60% portion of the tank because the liquid surrounding it requires 100 min. to flow through the entire length of the tank.

Detention time can be calculated by use of two known factors:

1. Flow in gallons per day.
2. Tank Dimensions

Example:

The flow is 3 million gallons per day, tank dimensions are 60 feet long by 30 feet wide by 10 feet deep. What is the detention time?

Detention Time, Hrs.:

$$\frac{\text{Tank Volume, cu. ft.} \times 6.24\ \text{gal/cu. ft.} \times 24\ \text{hr./day}}{\text{Flow, gal/day - (2,500,000)}}$$

Tank Volume, cu. ft. = Length, ft. x width, ft. x depth, ft.

Calculations:

Tank Volume, cu. ft. = length, ft. x width, ft. x depth, ft.
= 60 ft. x 30 ft. x 10 ft.
= 18,000 cu. ft.

Detention Time, Hrs. =

$$\frac{\text{Tank Volume, cu. ft.} \times 6.24 \text{ gal/cu. ft.} \times 24 \text{ hr./day}}{\text{Flow, gal./day}}$$

$$= \frac{8{,}000 \text{ cu. ft.} \times 6.24 \text{ gal./cu. ft.} \times 24 \text{ hr./day}}{2{,}500{,}000 \text{ gal/day}}$$

$$= \frac{2{,}700{,}000 \text{ gal./hr./day}}{2{,}500{,}000 \text{ gal./day}}$$

$$= 1.08 \text{ hours} \qquad \begin{array}{r} 24 \\ \underline{\times\ 6.24} \\ 149.76 = 150 \end{array} \qquad \begin{array}{r} 18{,}000 \\ \underline{\times\ 150} \\ 2{,}700{,}000 \end{array}$$

Weir Overflow Rate

Wastewater leaves the clarifier by flowing over weirs and into effluent troughs or some type of weir arrangement. The number of lineal feet of weir in relation to the flow is important to prevent short circuits or high velocity near the weir or the launder which might pull settling solids into the effluent. The weir overflow rate is the number of gallons of wastewater that flow over one lineal foot of weir per day. Most designers recommend about 10,000 to 20,000 gallons per day per lineal foot of weir. Under certain circumnstances higher weir overflow rates have been used for materials with a high settling rate or for intermediate treatment. However, secondary clarifiers and high effluent quality requirements of certain primary clarifiers generally need lower weir overflow rates. The calculation for weir overflow rate requires two known factors (1) flow in gallons per day; and (2) lineal feet of weir.

An Example:

The flow is 5.0 mgd in a circular tank with a 90 ft. weir diameter. What is the weir overflow rate?

$$\text{Weir Overlow, gpd/ft.} = \frac{\text{Flow Rate, gpd}}{\text{Length of Weir, ft.}}$$

$$\text{Length of Circular Weir} = 3.14 \times \text{Weir Diameter, ft.}$$

Calculations:

$$\text{Length of Circular Weir, ft.} = 3.14 \times (\text{Weir Diameter, ft.})$$

$$= 3.14 \times 90 \text{ ft.}$$

$$= 283 \text{ Lineal ft.}$$

```
  3.14
    90
282.60
```

$$\text{Weir Overflow, gpd/ft.} = \frac{\text{Flow Rate, gpd}}{\text{Length of Weir,ft.}}$$

$$= \frac{5{,}000{,}000 \text{ gal/day}}{283 \text{ ft.}}$$

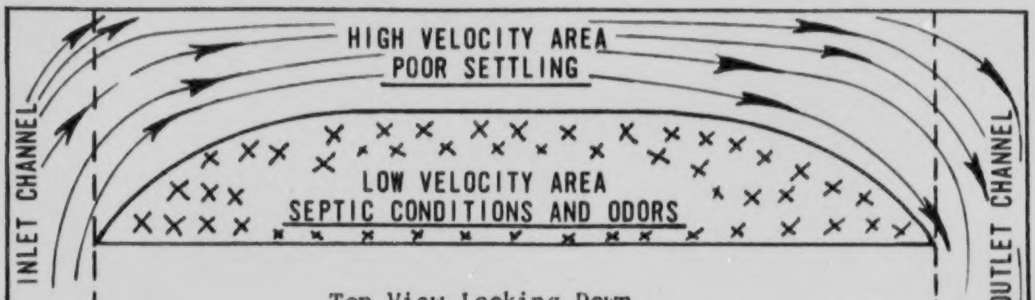
$$= 17{,}668 \text{ gpd/ft.}$$

```
       17,668
283 5,000,000
    2 83
    2 170
    1 981
      189 0
      169 8
       19 20
       16 98
        2 220
        2 264
```

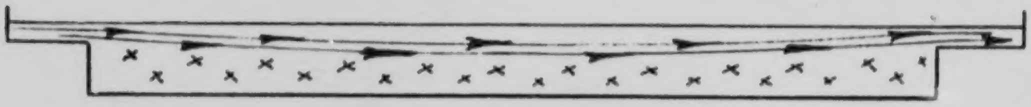
67

Short Circuiting

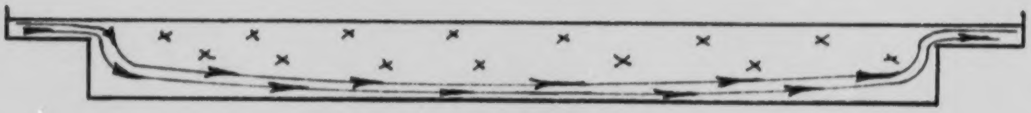
As the wastewater enters the clarifier, it should be evenly dispersed across the entire cross-section of the tank and should flow at the same velocity in all areas towards the discharge end. When the velocity is greater in some sections than in others, serious short circuiting may occur. Short circuiting also may be caused by turbulence stratification of density layers due to temperature or salinity of the wastewater.


HIGH VELOCITY AREA
POOR SETTLING
LOW VELOCITY AREA
SEPTIC CONDITIONS AND ODORS
INLET CHANNEL
OUTLET CHANNEL

Top View Looking Down



Side View - Warm Influent



Side View - Cold Influent

Fig. 3-1 - Short circuiting

GREASE REMOVAL

In wastewater, the fats, waxes, oils, fatty acids and other non-fatty materials are collectively called grease or scum.

Under quiescent conditions, a part of the grease settles with the sludge in the clarifier, while the other flows to the surface were it may be removed by a suitable skimming device.

Occasionally grease removal can be hastened by blowing air into the wastewater. The small, rising air bubbles attach themselves to the grease particles, increasing their buoyancy and entrapping them in the surface foam.

In rectangular clarifiers the floating material is moved to one end of the tank by sludge collector **flites** In circular clarifiers, floating material is usually moved to a skimmer by a surface blade attached to the sludge collector.

The floating grease or surface scum in the clarifier may be removed either mechanically or manually. To prevent the carry over of scum over the clarifier weir it should be removed before any appreciable amounts are allowed to accumlate on the scum barrier. However, excessive skimming should not be practiced because this will result in too much water being carried over with the scum into the grease pit. In rectangular tanks, without automatic skimmers, it is a good practice to remove the scum manually after the flights have made one complete revolution. However, each operating staff should determine by experience the pattern best suited for its particular plant.

SUBJECT:

DIGESTER OPERATIONS

TOPIC: 4

ANAEROBIC DIGESTION

OBJECTIVES:

The trainee will be able to:

1. Recall the objectives of Sludge Digestion.
2. Discuss the principles of the Anaerobic Digestion Process.
3. List the parameters which must be controlled for good digester operation.
4. Show by a simple diagram the Anaerobic Digestion Process.
5. Name five objectives which mixing can attain in the Anaerobic Digestion Process.
6. Name the three temperature ranges at which a digester may be operated.
7. Name and discuss four means used to heat a digester.
8. Understand and discuss single stage and two-stage digester operation.

ANAEROBIC
DIGESTION OF SLUDGE

OBJECTIVES OF SLUDGE DIGESTION

Settled solids and floating scum removed from the sedimentation tanks and clarifiers consist of a watery, malodorous mixture called raw sludge. In the majority of the plants this raw sludge is pumped to a digester for treatment before disposal. The primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge to a material that is relatively odour free, can be readily dewatered, capable of being disposed of without causing environmental problems, and which will undergo little or no further decomposition. Digestion of sludge can be carried out either by anaerobic or aerobic processes. **Topic 8 deals with the aerobic process.**

ANAEROBIC DIGESTION PROCESS PRINCIPLES AND THEORY

In the anaerobic process the organic solids, are liquefied and brought into solution by a catalyst called enzymes present in the sludge. The organic material is then broken down by the action of two different groups of bacteria living together in the same environment. One group consists of microorganisms commonly referred to as acid formers. The second group, which utilize the acid formed by the acid formers are methane fermenters, commonly referred to as methane formers.

The digestion process is normally described in three stages:

1. Acid fermentation stage
2. Acid regression stage
3. Alkaline fermentation stage

Acid Fermentation Stage

During the acid fermentation stage, the organic compounds, principally carbohydrates, are broken down to volatile fatty acids, primarily acetic, butyric and propionic acids. This production of volatile acids results in a drop in pH and causes putrefactive odours. The organisms primarily responsible for this stage of digestion are the acid formers. This group encompasses a large number of bacteria which are anaerobic or facultatively anaerobic. As a rule, the acid formers are very vigorous reproducers and are less sensitive to environmental factors than the methane formers.

Acid Regression Stage

During the acid regression stage, decomposition of organic acids (volatile acids) and soluble nitrogenous compounds occurs which result in the formation of the following principal compounds:

1. ammonia
2. amines
3. acid carbonates

During this stage the pH will tend to increase.

Alkaline Fermentation Stage

During the alkaline fermentation stage, destruction of nitrogenous compounds and cellulose occurs. The volatile organic acids, produced during stage 1 of the process are broken down to produce carbon-dioxide (CO_2), methane (CH_4) and water. The principal organisms responsible for this process are the methane formers.

These organisms are strictly anaerobic, are a slower reproducing bacteria, and are much more sensitive to their environment than the acid formers. These organisms reproduce most effectively in the pH range of 6.8 - 7.2 although experience has shown that satisfactory digestion will continue at the pH range of 6.5 - 7.5.

These three stages occur continuously and, for all practical purposes, simultaneously.

DIGESTER OPERATION CRITERIA

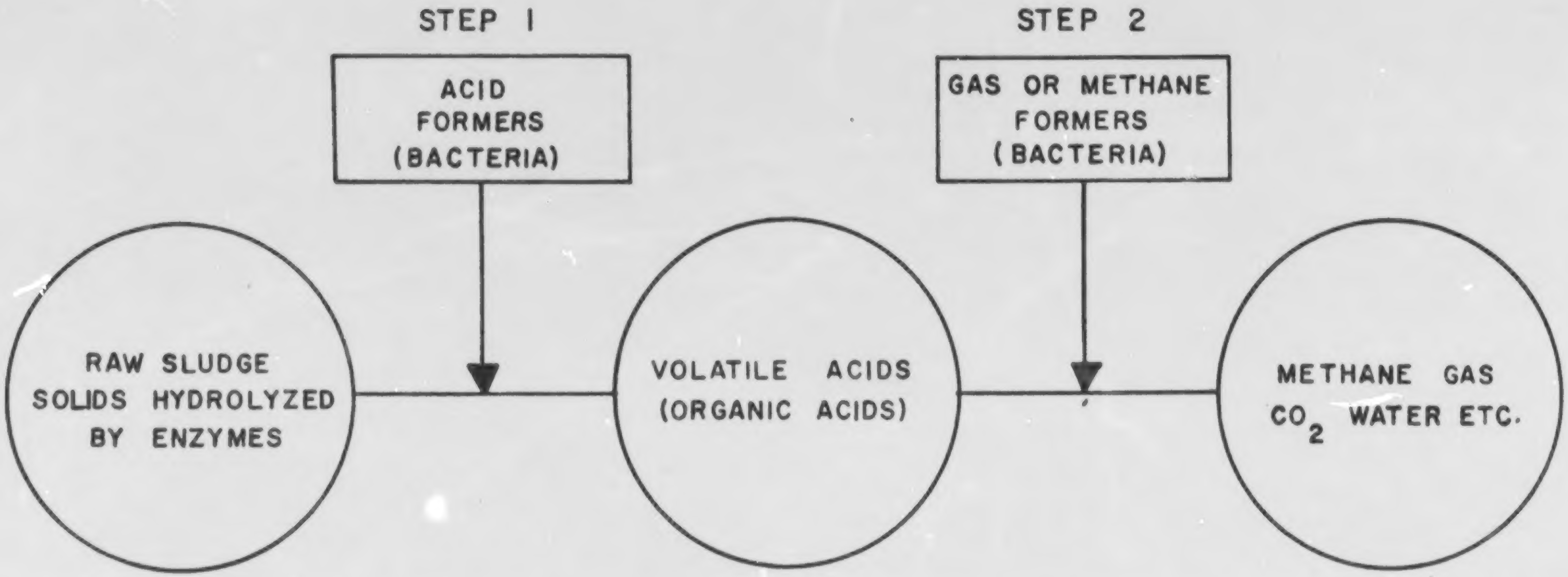
The basic criterion for good digester operation is the maintenance of a suitably balanced environment in the digester for the growing or reproducing of both acid formers and methane formers. To maintain this balance in the process the operator must exercise control over the following parameters:

1. food supply (raw sludge loading rate)
2. volatile acids/alkalinity relationship
3. mixing of the digester contents
4. temperature

Generally, in an efficient digester operation the volatile solids content of the sludge is reduced by 40 to 60 per cent. The time required to digest the sludge, may be from two weeks to four months duration and is dependant upon the above parameters. **Figure 4-1** illustrates in simple equations what happens in the digester.

It is important to note that the methane forming organisms are more sensitive to upset and reproduce at a slower rate than the volatile acid formers. Every effort should be made to operate the anaerobic digester in a manner whereby the rate of acid formation is kept in balance with the production of methane. The most common cause of digester upset that occurs in the process is that of the methane gas formers failing to keep pace with the acid forming organisms with the result that the digester becomes overly acidic. When a buildup of this acid condition develops, the rate of the digestion process will begin to slow, and if left unchecked will result in serious inhibition or even complete failure of the digestion process. As acid concentrations increase, pH levels drop. The optimum range for a good digestion process is a pH value of 6.8 to 7.2. pH values lower than 6.8 might indicate a process failure. However, experience has shown that the digester process upset will be far advanced before the reduction in pH will indicate a problem. The volatile acids test and the

ANAEROBIC DIGESTION PROCESS



STEP I

ACID
FORMERS
(BACTERIA)

STEP 2

GAS OR METHANE
FORMERS
(BACTERIA)

RAW SLUDGE
SOLIDS HYDROLYZED
BY ENZYMES

VOLATILE ACIDS
(ORGANIC ACIDS)

METHANE GAS
CO_2 WATER ETC.

FAILURE OF STEP 2 WHILE STEP I CONTINUES CREATES AN EXCESS OF ACIDS REDUCING PH AND FINALLY CAUSING TOTAL PROCESS FAILURE.

FIGURE 4-1

alkalinity test have proven more useful and effective in predicting and avoiding process failures. In general, there is a relationship between acids and alkalinity which will remain fairly constant during satisfactory digestion. The alkalinity is always greater than the volatile acids concentration to some degree. A fairly rapid increase in volatile acids with an associated decrease in alkalinity indicates an impending process upset. Should the alkalinity concentration be allowed to drop to a level lower than that of the acids, all digester buffering capacity will be lost, the pH will very rapidly drop to a level well below 7.0 and the process could be considered as having failed. Such an upset is usually accompanied by poor gas production and quality and perhaps by foaming. Careful monitoring therefore, of the alkalinity and acids concentrations, will provide warning of an impending process upset, as opposed to pH showing process upset after the fact, and various measures can be taken to avert complete digestion failure. Such measures are described in detail later in the text.

REACTIONS IN DIGESTION PROCESS

Raw Sludge Complex Substrate Carbohydrates Fats Proteins	+	Microorganisms "A" Principally Acid Formers Saprophytic Facultative	$\longrightarrow$	CO_2, H_2O Intermediate Degradation Products	+	Organic Acids Cellular & Other Intermediate Degradation Products
Organic Acids Cellular & Other Intermediate Degradation Products	+	Microorganisms "B" Principally Methane Formers Obligate (?) Anaerobes	$\longrightarrow$	CH_4 + CO_2 Methane Carbon Dioxide	+	Other End Products H_2O, H_2S and Degradation Products

MIXING

Mixing is an important factor in the process and should accomplish the following:

1. Utilize as much of the total volume of the digester as possible.
2. Quickly distribute the raw sludge throughout the digester and put the micro organisms in rapid contact with fresh food sources.
3. Achieve good pH control by distributing buffering alkalinity throughout the digestion tank.
4. Obtain the best possible distribution of heat throughout the tank.
5. Minimize the deposition of grit and inert solids on the bottom, or floating scum material to the top.

Mixing the tank contents completely, speeds the digestion process greatly.

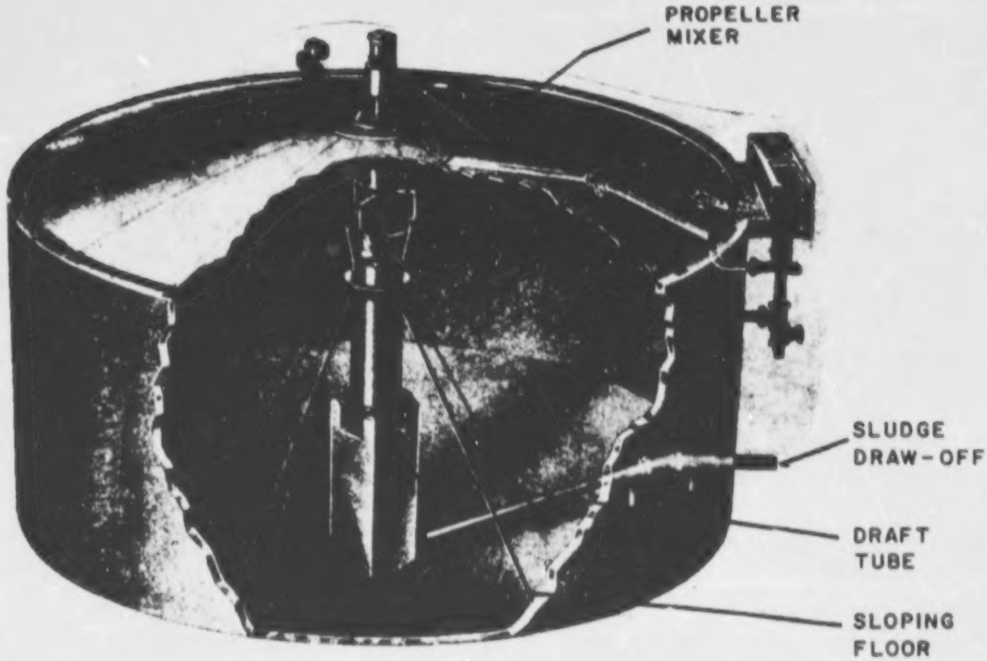
Mixing can be accomplished by various means:

1. By mechanical mixers.
2. By digester gas recirculation.

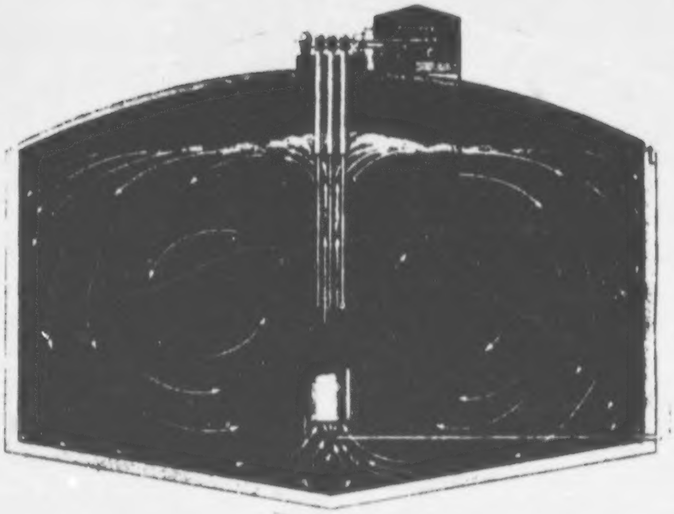
Some mixing action is also contributed by recirculating sludge through the heat exchanger.

Mechanical Mixing

The propeller-type mixers are found mainly on fixed-cover digesters. Normally, two or three of these units are supported on the roof of the tank. Electric motors drive the mixers. A typical propeller-type mixer is shown in Figure 4-2. It is usual for mixing action and control to be enhanced by the installation of draft tubes to serve the mixers. The draft tubes are steel and range from 18 to 24 inches in diameter. The top of the draft tube has a rolled


PROPELLER MIXER
SLUDGE DRAW-OFF
DRAFT TUBE
SLOPING FLOOR

MECHANICAL MIXER
(COURTESY OF DORR-OLIVER, INC.)



GAS RECIRCULATION MIXER
(COURTESY OF WALKER PROGRESS INC.)

FIGURE 4-2 MIXERS

lip and is located approximately 18 inches below the normal water level in the tank. The bottom of the draft tube may be straight or equipped with a 90-degree elbow. The 90-degree elbow type is placed so that the discharge is along the outside wall of the tank to crease a vortex (whirlpool) action.

The mixer propeller is located about two feet below the top of the draft tube. This type of unit usually has a reversible motor so that the prop may be rotated in either direction. In one direction the contents are pulled from the top of the digester and forced down the draft tube to be discharged at the bottom. By operating the motor in the opposite direction, the digested sludge is pulled from the bottom of the tank and is then discharged over the top of the draft tube near the surface. If the digester is equipped with two units, an effective method in breaking up a scum blanket is by operating one unit in one direction and the other unit in the opposite direction, thereby creating a push-pull effect. Mechanical mixers are sometimes subject to shaft-bearing failure due to the abrasiveness of the sludge, and corrosion by hydrogen sulphide present in the digester gas. Maintenance consists of lubrication and, if belt-driven, adjustment of belt tension.

The drawback of a draft-tube-type mixer is related to the digester sludge level. If the sludge level is maintained at a constant elevation, a scum blanket may form on the surface. When the scum blanket becomes thick the mixer will only pull the liquid sludge from under the blanket and not disturb the scum itself. Lowering the level of the digester to just 3 or 4 inches over the top of the draft tube may help to force the scum to move over and down the draft tube. This particularly applies to single direction mixers.

Pumps are sometimes used to mix digesters. This method is common in smaller tanks. When external heat exchangers are utilized, a larger centrifugal pump is used to recirculate the sludge and discharge it back into the digester through one or two directional nozzles at the rate of about 200 to 1000 gpm.

The tank may or may not be equipped with a draft tube such that the pump suction can be from the top or the bottom of the digester. Control of scum blankets with this method of mixing is dependant upon how the operator maintains the sludge level and where the pump is pulling from and discharging to the digester.

Maintenance of the recirculating sludge pump requires normal lubrication and a good pump-shaft water sealing system. The digested sludge is abrasive and pump packing, shaft, wearing rings, and impellers are rapidly worn. Another problem associated with pump mixing is clogging of the pump impeller with rags, plastic materials, rubber goods and other pieces of material which can wind around the impeller causing it to plug.

It is very important to check pump operation several times a day.

Pressure gauges should be installed on the pump suction and discharge pipes. If a rapid increase in pressure differential is seen, the operator has an indication that pump clogging has occurred.

Mixing by Digester Gas Recirculation

In these systems, the digester gas is collected and fed by blowers to the bottom of the digester where it is exhausted through diffusers or "bubble-guns". Mixing of the sludge is accomplished as the gas rises to the surface. See Figure 4-2, Page 4-7.

HEATING AND TEMPERATURE CONTROL

RANGES OF DIGESTION TEMPERATURES

A digester may be operated in one of three temperature zones or ranges, each of which has its own particular type of bacteria. The lowest range (in an unheated digester) utilizes psychrophilic (cold temperature loving) bacteria. Temperature of the sludge inside tends to adjust to the outside temperature. However, below 10°C (50°F) little or no bacterial activity occurs and the required reduction in sludge volatile solids (organic matter) will not likely occur. When the temperature rises above 50°F the bacterial activity increases and the digestion process improves. The bacteria appear capable of surviving temperatures well below freezing with little or no harm. The psychrophilic digestion upper unit is around 20°C (68°F). Digestion in this range requires from 50 to 180 days, depending upon the degree of treatment required. Generally, these digesters are not very effective in digesting sludge.

The middle range of organisms are called the mesophilic (medium temperature loving) bacteria; they thrive between a temperature of 20°C and 35°C (68° and 113°F). This is the most common operational range, with temperatures usually being maintained at about 35°C to 37°C (95° to 98°F). Digestion at that temperature may take from about 25 to 30 days, depending upon the required degree of volatile solids reduction and the adequacy of mixing. The high rate processes are usually operated in the mesophilic temperature range. The high rate process is a procedure providing mixing so that the organisms and the food source can be brought together to allow the digestion process to proceed more rapidly.

The third range of organisms are called the thermophilic (high temperature loving) bacteria, and they thrive between 120° and 140°F. The time required for digestion in this range may be between five and twelve days, depending upon the operation and the degree of volatile solids reduction required. However, few plants have actually been operated in the thermophilic range of temperatures and there is little documentation of results.

When operating a digestion system in any of these temperature ranges, care must be taken to maintain a more or less constant temperature.

HEATING SYSTEMS

Digester heating can be accomplished by the following means:

1. Hot-water coils within the digester.
2. Recirculating sludge through an external heat exchanger.
3. Direct contact of hot gas with sludge.
4. Steam injection.

External Heat Exchanger

The most common of the four is the recirculation of sludge through an external heat exchanger. Hot water is pumped from the boiler to the heat exchanger where it passes through a jacket while the recirculating sludge passes through an adjacent jacket, and receives heat from the water. In some heating installations the boiler and exchanger are combined in a single unit. There are some advantages in using external heat exchangers. These are: they help to control scum buildup and there is no hotwater piping within the digester which can be corroded or caked up. The only disadvantage is that in a single stage digester system it is essential to stop sludge recirculation to allow the tank contents to stratify prior to the discharge of supernatant. This can result in an increased tendency to form a "cake" on the exchanger coils, or jackets due to localized overheating of the sludge.

Hot-Water Coil

Hot-water coils within the digester consisting of pipes either horizontally or vertically attached to the inside wall of the digester is another method of heating digesters, although not too common in newer plants. This method tends to create a problem of sludge caking on the pipes and thereby effectively insulating them, thus reducing the amount of heat transferred. Where coils are used water temperatures entering the coils are limited to a temperature of 120 to 130°F, with boiler temperatures held to no higher than 180°F, to prevent excessive corrosion or caking of the sludge on the coils.

Direct Contact and Steam Injection

Direct contact of hot gas with sludge and steam injection methods have been used in the past with varying degrees of success. However, these systems are rarely installed in current practice.

SINGLE-STAGE DIGESTION

For simplicity, single-stage digester operation will be covered under four headings:

1. Loading
2. Process
3. Supernatant Selection
4. Digested Sludge Removal

LOADING

Ideal conditions would be met if the raw sludge could be pumped continuously to the digester. In practice, however, for various reasons, continuous loading is not possible. Some small plants, receiving eight hours per day of operator's supervision, may load the digester three times a day, say at about 8 o'clock in the morning, 12 noon, and 4 in the afternoon. When automatic pumping facilities are provided, the other extreme may be reached with loading being effected once each hour. Where supervision is provided on a 24-hour basis, manual controls may dictate 6 to 8 pumping cycles per day. Excess amounts of primary effluent may be directed to the digester if too many pumping cycles are provided due to exhaustion of raw sludge supply. In installations where raw sludge must be pumped long distances to the digester, the sludge line must be filled with diluted sludge before the pump is shut off, to prevent plugging. The next pumping cycle will direct the diluted sludge to the digester.

In a single stage operation, the raw sludge is directed to the top half of the digester. As indicated in the Flow Diagram appended as Figure 4-3, the raw sludge may be mixed with seed sludge leaving the heat exchanger.

PROCESS CRITERIA

The same process parameters apply to single-stage digestion as multi-stage digestion with the following operational techniques being peculiar to the single-stage process:

SINGLE STAGE UNIT.

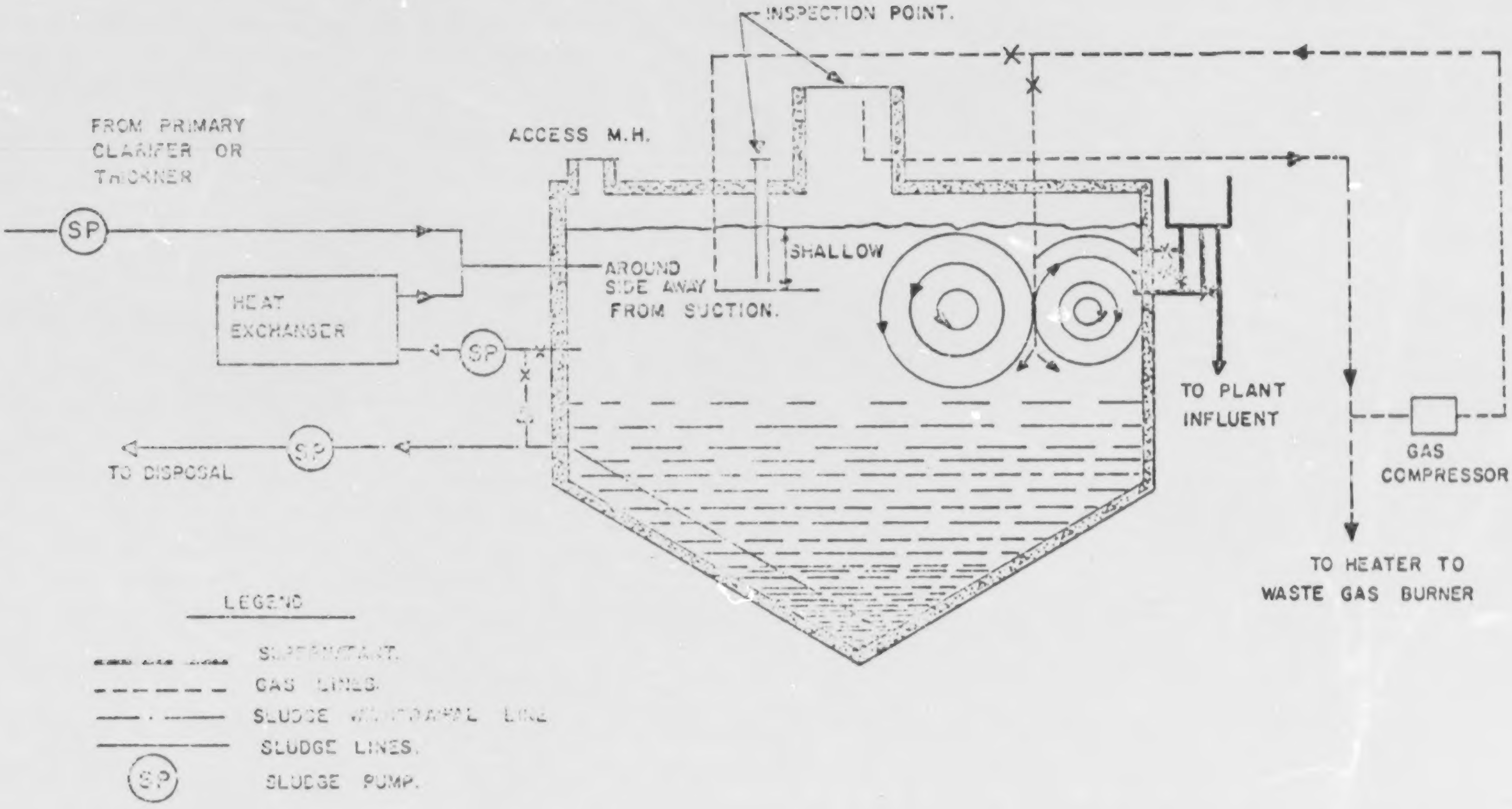

INSPECTION POINT.
FROM PRIMARY CLARIFER OR THICKNER
ACCESS M.H.
SP
SHALLOW
AROUND SIDE AWAY FROM SUCTION.
HEAT EXCHANGER
SP
TO PLANT INFLUENT
GAS COMPRESSOR
TO DISPOSAL
SP
TO HEATER TO WASTE GAS BURNER
LEGEND
SUPERNATANT.
GAS LINES.
SLUDGE WITHDRAWAL LINE
SLUDGE LINES.
SP
SLUDGE PUMP.

FIGURE 4-3

1. Mixing

   In a single stage unit, mixing facilities, if any, are designed only to mix the material in the top half of the tank. In practice, this type of a design makes it almost impossible to operate an efficient digestion system. Thus it is difficult to obtain a concentrated sludge from a single-stage digester operation.

   In a single-stage digester an improper mixing program could lead to the process failure. The active volume for the digester process can be greatly reduced by:

   a) The formation of scum or sludge blankets.

   b) Foaming occurring when the scum blanket begins to digest.

2. Temperature

   The importance of temperature has been discussed in Section (Digester Systems). The major objective here is to maintain the sludge temperature to within, say, $\pm 1^{o}C$ ($\pm 33^{o}F$).

SUPERNATANT SELECTION

In a single stage digester it is difficult to obtain a good supernatant. Nevertheless, an attempt should be made to remove any excess liquid. Mixing devices should be shut off for a period of time before the supernatant is withdrawn. Through experience, the operator will learn the duration of the quiescent settling period required to obtain an optimum supernatant.

In digesters where a variable level of supernatant selection is provided, the supernatant is removed via the line proving to be the most satisfactory. An example of a supernatant selector system is appended in Figure 4-4. In simpler installations the withdrawal control is maintained by a sleeve-height adjustment. Other installations use valves to control these withdrawal processes. It should be noted that in all installations the safety overflow

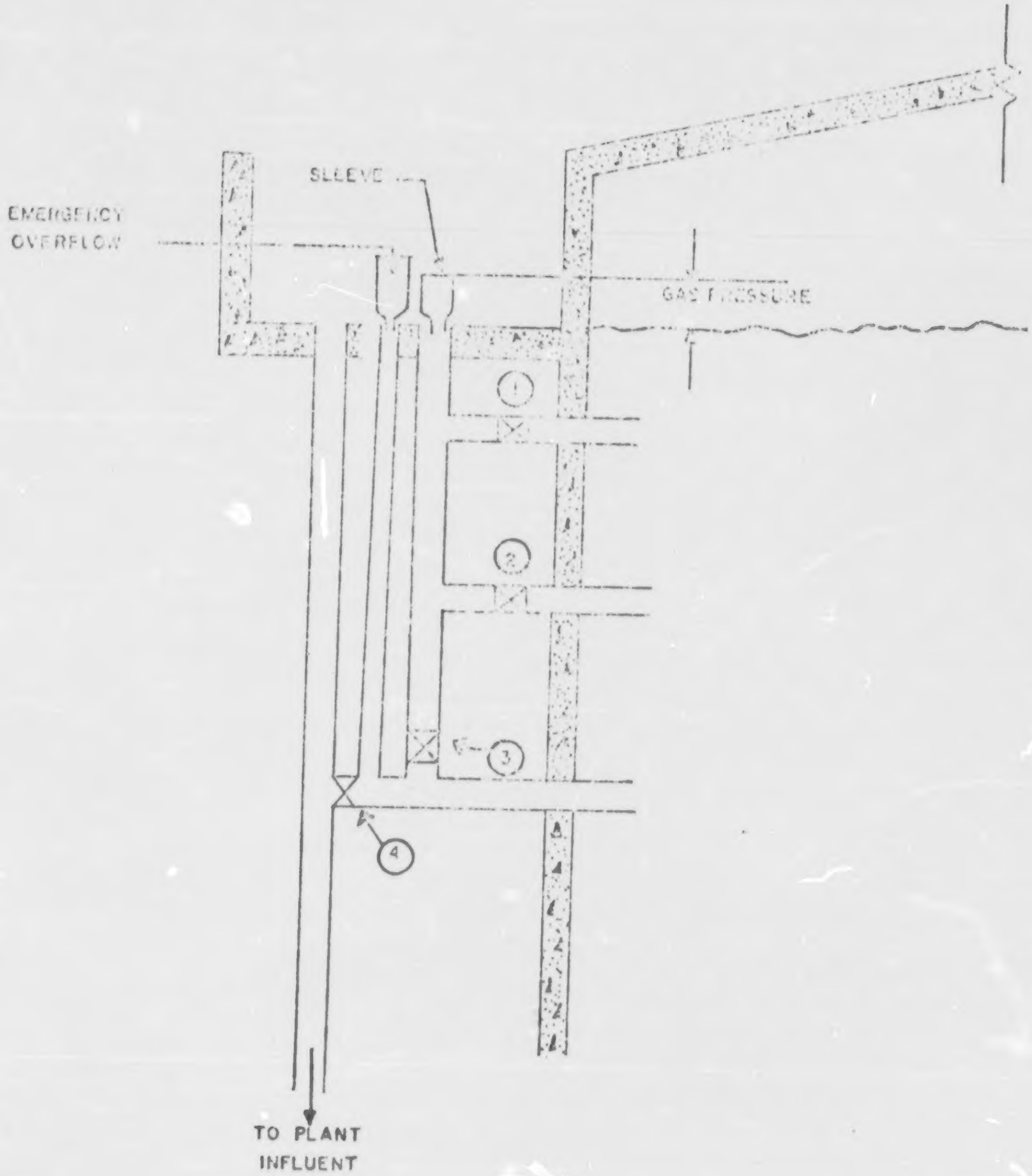

SLEEVE
EMERGENCY OVERFLOW
GAS PRESSURE
1
2
3
4
TO PLANT INFLUENT

Figure 4-4
SUPERNATANT SELECTOR

should be kept open at all times. To check the efficiency of the supernatant withdrawal process the operator should carry out a series of suspended solids tests. For quick results, the test can be carried out by using a centrifuge with the standard suspended solids test being used where complete laboratory equipment is available. In a good supernatant a suspended solids concentration of 3,000 to 10,000 mg/l might be seen, although many supernatants have solids levels for exceeding these concentrations.

DIGESTED SLUDGE REMOVAL

In a single stage digestion system the accumulated sludge should be removed as frequently as possible. It may be difficult to obtain a good concentrated sludge from this type of system. A 3 to 4 per cent sludge may be considered good for the digested sludge obtained from an activated sludge plant using a single-stage digestion process. In a digester equipped with a fixed cover and from which digester gas is used to operate other components of the treatment system, the digested sludge is best removed when the raw sludge is being pumped to the digester. This practice will assist in maintaining the gas pressure in the tank, and will tend to avoid a vacuum being formed.

WARNING

The withdrawal rate of sludge from the digester with a fixed roof should be no faster than the rate of input of raw sludge. If the draw-off rate is too fast, the gas pressure drops due to volume expansion. This practice may create an explosive hazard by drawing air into the digester, through the pressure-vacuum relief valve.

TWO STAGE DIGESTION

GENERAL

Two stage digestion is covered under five headings:

1. Sludge Loading
2. Process Criteria
3. Sludge Transfer
4. Supernatant Selection
5. Digested Sludge Removal

SLUDGE LOADING

Where mixing is practised the raw sludge may be directed to any point in the first-stage tank. Ideally, as with most biological systems, a constant sludge feed rate would be preferred. However, in practice, sludge is fed on a cyclical basis, usually by timers, although manual operation may be featured from place to place. The feeding cycles should be frequent and preferably made over a 24-hour period although in smaller plants, the feeding might be accomplished over an 8-hour period. A good two-stage design will allow the use of either tank for the first stage. An example of a Two-Stage Digester Diagram is appended in Figure 4-5.

PROCESS CRITERIA

Where mixing devices are available they are operated to control the scum blankets and minimize inactive or dead spaces, and to bring bacteria and fresh food sources rapidly together. Mixing is carried out, in the first-stage digester, the mixing devices may be operated either full or part time. When part time operation is desired the cycle is set up in relation to test and observation of scum blanket formation and not on power saving. In some operations the mixers may be operated only a few hours a day. It should be emphasized that full-time mixing is, however, the preferred practice.

An improper mixing program could result in process failure. The active volume available for the digestion process can be greatly reduced by the formation of a scum blanket or formation of foam when the scum blanket begins to digest. In two-stage digesters which are not equipped with positive mixing devices the scum blankets may be partly controlled by the use of compressed air to mix the tank contents. This control measure may be carried out two or three times a year, depending on need. Caution: when using air for mixing, great care must be taken to ensure that the explosive air/gas mixture is not ignited. Obtain the services of a qualified Safety Officer. Forbid smoking in plant area, use rubber footwear, use no-sparking tools and do not bang pipes so as to cause a spark at digester opening. Also, open as many manholes as possible for ventilation.

Temperature in the secondary digester normally is from 3°to 5° Centigrade below that of the primary unit. Under normal conditions, this makes heating of the secondary digester unnecessary except during the coldest part of the year. But if satisfactory digestion is not obtained, it may be necessary to increase the temperature. It should be remembered that the optimum mesophilic digestion is carried out at between 33 and 35 degrees C. However, lower temperatures may be used where excess digester capacity is available allowing long sludge retention times.

In digesters where heating is provided by external heat exchangers, the operator should recirculate warm supernatant to the top of the scum layer at the centre of the tank and preferably at one or more additional points. This procedure will not only increase the temperature of the scum blanket, but will increase the moisture content of the blanket thus aiding digestion and increasing its specific gravity causing it to settle and mix with the rest of the materials in the digester.

SLUDGE TRANSFER

Sludge can be transferred from the first-stage digester to the second-stage digester by a number of methods, three of which are as follows:

1. Automatic transfer may be effected by using an equalizing line, as shown on Diagram Figure 4-5.
2. Sludge may be transferred using the heat exchange unit recirculating line.
3. Bottom sludge may be pumped to the second stage unit directly.

Most of the sludge digestion is accomplished in the primary digester and 90% of the gas production occurs there. The secondary digester is used basically as a holding tank for separation of the solids from the liquor and to allow some further digestion of the volatile matter in the sludge. To accomplish this the secondary digester must be quiescent or with as little mixing as experience deems necessary. Therefore on a normal operation process, when raw sludge is pumped to the primary digester, an equal volume is transferred to the secondary digester and settled supernatant from the secondary digester is returned to the plant. Nevertheless, at least once a week, transfer of sludge must be made from the bottom of the first-stage tank. If this is not done the bottom withdrawal line will plug up with grit or heavy compacted solids.

SUPERNATANT SELECTION

In a two-stage digestion system the supernatant is obtained from the second digester. The supernatant can be selected automatically when a sludge transfer takes place or as a manual operating procedure when the plant can best receive the extra BOD loading. In either the fixed-cover or the floating-cover installations, the operator should select the best quality supernatant for withdrawal. By observing and sampling material from the various supernatant sampling lines, the operator can determine the depth of the best material. Automatic quality selectors are

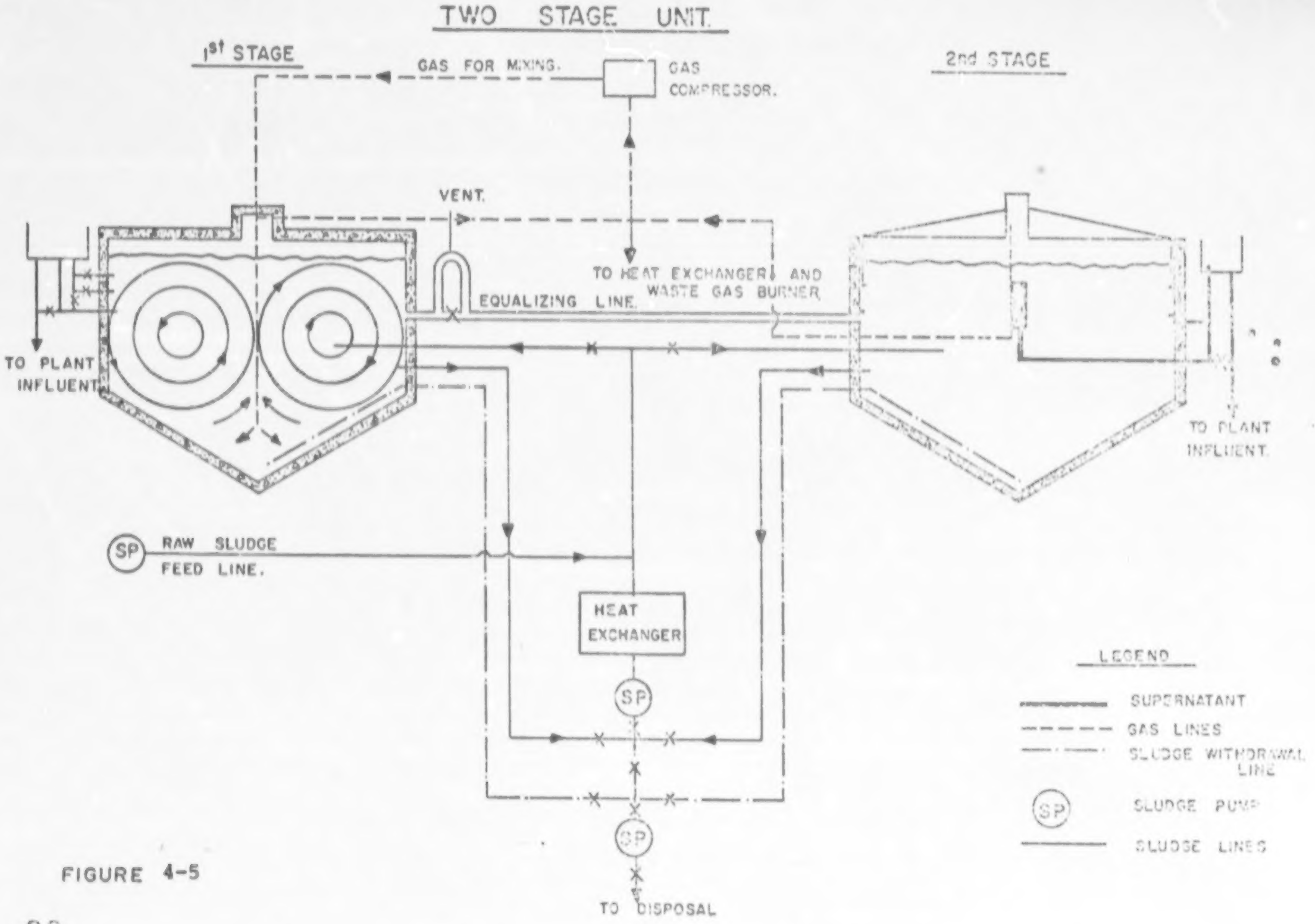

TWO STAGE UNIT
1st STAGE
GAS FOR MIXING.
GAS COMPRESSOR.
2nd STAGE
VENT.
TO HEAT EXCHANGER AND WASTE GAS BURNER
EQUALIZING LINE.
TO PLANT INFLUENT
TO PLANT INFLUENT.
SP
RAW SLUDGE FEED LINE.
HEAT EXCHANGER
SP
SP
TO DISPOSAL
LEGEND
SUPERNATANT
GAS LINES
SLUDGE WITHDRAWAL LINE
SP
SLUDGE PUMP
SLUDGE LINES

FIGURE 4-5

sometimes installed for this purpose. They should be checked for effectiveness quite frequently and backflushed when they become clogged.

DIGESTED SLUDGE REMOVAL

Digested sludge should be withdrawn as soon as it has reached a reasonably good stage of digestion as determined from its volatile content or at a rate commensurate with minimal supernatant discharges. In a fixed-cover installation the sludge must be removed in small batches. If this is not done the gas pressure will not be maintained. On the other hand, in a digester equipped with a floating cover, the sludge settled in a second-stage unit may be removed more or less as convenience requires; moderately large withdrawals will not cause process failure or loss of gas pressure.

SAFETY CONSIDERATIONS

When withdrawing sludge from a fixed-cover unit, air may be drawn into the digester creating possibly explosive gas mixtures unless the rate of sludge replacement is equal to the rate of withdrawal. Equal care must be exercised to keep the liquid level above the stops of a floating cover if creation of a vacuum is to be prevented in the tank. For most efficient operation of the digestion system the withdrawal rate of the sludge from either digester should be no faster than the rate at which the gas production from the system is able to maintain a positive pressure in the digester (at least two inches of water). If the draw operation is too fast the gas pressure drops due to volume expansion. Some operators prefer to pump raw sludge to the digester during digested sludge drawoff to maintain the required positive pressure.

SUBJECT:
DIGESTER OPERATIONS

TOPIC: 5
MONITORING AND CONTROL

OBJECTIVES:

The trainee will be able to:

1. Recall the tests and records required to maintain process control in anaerobic digestion.
2. Discuss foaming and gas production problems and possible remedies.
3. List four potential causes of digester process failure.
4. Discuss three methods which may overcome digester process failure.

DIGESTER PROCESS

MONITORING AND CONTROL

GENERAL

Although digestion is a complex process and not all of the microbiological theory is understood, enough is known to allow the operator to exercise good operational control. For successful operation of the sludge digestion process, as for any other portion of the wastewater treatment process, there is no substitute for an understanding of the theory of the process and systems so that the operator knows what the objectives are and how they can be achieved.

Topic 4 discussed in some detail the theory and principles of digestion, as well as some methods by which efficient operations can be achieved. The operator has other means whereby he can control and facilitate the process. These include:

1. Closely controlling grit and skimming in order that the capacity of the tank is affected as little as possible by these materials. Several small additions are more desirable than one large discharge.
2. Having a good maintenance program to maintain a maximum degree of flexibility.
3. Maintaining records and laboratory control in order that process condition is known at all times.
4. A thorough knowledge of the process and equipment.

As with any treatment system, the anaerobic digestion process must be sampled and monitored to provide operational and performance data.

PROCESS MONITORING

The following show the analyses which should be conducted upon the various streams:

1. Raw Sludge: pH, Total Solids, Volatile Solids
   These analyses should preferably be conducted weekly, although a longer frequency may be satisfactory where digester retention times are greater than 30 days.

   Raw sludge feed rates should be noted daily.

2. Primary Digester Sludge (in two-stage system):
   pH, Total and Volatile Solids, Volatile Acids, Alkalinity
   Solids analyses should be conducted on the same frequency as for Raw Sludge. Alkalinity, Acids and pH should be conducted 2-3 times a week if possible, to provide up-to-date information on the condition of the process. In addition, digester temperature and gas production should be noted daily.

3. Digested Sludge: pH, Total and Volatile Solids, Heavy Metals
   These analyses should be conducted on the same frequency as those for raw sludge.

   In addition, digested sludge removal rates should be carefully noted. In two-stage systems, secondary digester temperature and gas production rates should be monitored daily. The physical characteristics of the digested sludge should also be noted, for example, black and granular or brownish and gelatinous.

4. Supernatant
   As some of this stream will be discharged to the activated sludge section of the plant, it should be regarded essentially as an industrial waste and its pollutional characteristics fully measured.

For example, the following analyses should be conducted: pH, Total and Volatile Solids, Heavy Metals, BOD, Free NH_3, Total Kjeldahl, Phosphorus, TOC. These should be conducted on the same frequency as those for Raw Sludge.

It is important to remember that digester supernatant is very high in pollutional potential and that any discharges to the activated sludge section should be small and made during low flow conditions. If supernatant is discharged to the aeration tanks at times of peak loading, the bacteria and aeration equipment may be inundated by the likely excessive organic load, and result in an upset producing a poor final effluent.

PROBLEM SOLVING

In the following section, some common digestion problems and their remedies are described.

Control of Foaming

Large amounts of foam may be generated for example, during a start-up period. Foaming is a result of active gas production while solids separation has not progressed far enough. It is usually caused during the start-up stage by over-feeding. Foaming can be controlled to some extend by adequate mixing of the digester contents.

Foam is a problem in that it not only plugs gas-piping systems, but can exert pressure on digester covers, cause odour problems, and seeping gases can ruin paint jobs on tanks and buildings in the area. Should this problem occur, to clean up the mess the operator will have to first drop the level of the digester a couple of feet by withdrawing some supernatant. Next, cut off the gas system and flush it with water. Then hose the outside of the digester off as soon as possible for the paint will be stained.

To control foaming, one method is to stir the tank gently to release as much of the trapped gas from the foam as possible. Some operators even stop mechanical mixing equipment and stir with long wooden poles. Try not to add too much water from any cleaning hoses as this reduces the temperature and dilutes the tank, which could create a condition for more foaming later. Do not feed the tank heavily, preferably not at all, until the foaming has subsided. There are also several commercially available antifoam emulsions which are effective in controlling foaming problems.

Foaming may also occur when a fixed sludge blanket is broken up, temperature changes radically, or the sludge feed rate to the digester is increased rapidly. The operator should avoid any conditions that give the acid formers the opportunity to produce more food than the methane formers can handle. It should be noted that foaming is usually a result of an upset elsewhere in the process and is not causative of upset in itself.

If steady-state operation and adequate mixing is applied, foaming problems are minimized; therefore, the mixing of the digester contents from top to bottom of the tank must be started in early stages of digester start-up, and any process changes, for example, feed rate or temperature variations, should be applied slowly and gradually.

Gas Production

When a digester is first started, extremely malodorous gases are produced, including a number of nitrogen and sulphur compounds such as skatole, indole, mercaptans, and hydrogen sulphide. Some of these are also produced during normal digestion phases, but they are generally so diluted by carbon dioxide and methane gases that they are hardly noticeable.

During the first phases of digester start up, most of the gas is carbon dioxide (CO_2) and hydrogen sulphide (H_2S). This combination will not burn and therefore is usually vented to the atmosphere. When methane fermentation starts and the methane content reaches around 60 per cent, the gas will be capable of burning. Methane production eventually should be predominating, generating a gas with 65%-75% methane and 30%-35% of CO_2 volume. Digester gas will burn when it contains 56% methane, but is not usable as a fuel until the methane content approaches 62%. When the gas produced is burnable, it may be used to heat the digester as well as providing heat in other buildings. If gas production and quality drop, the reasons for the process upset or failure must be found. These might include variations in raw sludge feed rate or quality or large temperature changes.

RECOVERY OF DIGESTION PROCESS

When a digestion process failure occurs, indicated by low gas production, poor quality gas, and an elevated volatile acid to alkalinity ratio, with low pH, the operator must immediately organize a recovery program. In setting up this program a most important task is to ascertain the actual reason for the process failure. It should be noted that low pH and abnormal acids-alkalinity ratios are indicative of digester upset and are not causative in themselves. There is no use in spending time and money to re-establish an anaerobic digestion process if the failure is to reoccur again at a later date. The process failure can be caused by one or a combination of the following:

1. Organic or hydraulic overloading
2. Inadequate or widely fluctuating temperatures
3. Inadequate Mixing
4. Metal Ion or Metal Toxicity

After the cause of the failure is thought to be known and corrected, a plan of recovery should be formulated and conducted.

POSSIBLE RECOVERY PROGRAMS

Removal of Sludge from the Digester

This is a drastic step and the least desirable. It may require a period of two months or more to re-establish the digestion. The disposal of sour sludge, from the digester, is a major job in itself and then seed sludge must be obtained to speed up the digester's start-up process. In the meantime a large portion of raw sludge must be hauled for farm or other methods of disposal.

pH Adjustment

The recovery of a sour digester can be accelerated by neutralizing the acids with a caustic material such as Soda Ash, lime or ammonia. Such neutralization increases the pH to a level suitable for growth of methane fermentors and provides buffer material which will help maintain the required volatile acid/alkalinity relationship and pH. When ammonia is added to a digester, an added load is eventually placed on the receiving water. The application of lime will increase the solids handling problem. Soda Ash on the other hand is more expensive than lime, but does not add as much to the solids deposit.

When neutralizing the pH in a digester, a prescribed dose must be carefully calculated. Too little of the chemical added will be ineffective, and too much is both toxic and wasteful. The lime must be mixed into a solution before addition to the digester because dry lime settles to the bottom in lumps and does not improve the process. Use all of the mixing facilities available while liming and thereafter in the digester mixing. The easiest application point is through the scum box if one is available. Add small quantities of lime daily until the pH and volatile acid/alkalinity relationship of the tank are restored to the desired levels and gas production is normal. In using lime for adjustment of pH, care must be taken that overdosing does not cause an ion toxicity problem in the digester. Overdosing with lime may result in the complete failure of the digestion process instead of recovery.

In considering dosage with lime, the small plant without laboratory facilities could use, as a rough guide, a dosage of about 1 lb. of lime added for every 1000 gallons of sludge to be treated. Thus, a 200,000 gallon digester full of sludge would receive 200 lbs. of lime. A more accurate method is to add sufficient lime to neutralize 100% of the volatile acids in the digester liquor. This can best be achieved where laboratory facilities are available. Below is an example showing the calculation for lime dosage.

Required: to neutralize a 150,000 gallon digester where the volatile acids are 4,000 mg/l.

$$\text{Qty. required} = 150{,}000 \times 10 \times \frac{4{,}000}{1{,}000{,}000} \times \frac{74}{60 \times 2} = 3{,}700 \text{ lbs.}$$

$$\text{Tank vol.} \times 10 \times \frac{\text{vol. acid con.}}{1{,}000{,}000} \times \frac{74}{60 \times 2}$$

Reduced or Stopped Loading and Secondary Sludge Return

When the digester process failure is not complete as indicated by acids, alkalinity and pH analyses, the most satisfactory method of recovery consists of the reduction or cessation of the raw sludge load. This measures, accompanied by the nation of secondary digester sludge, will hasten primary digestion process recovery in a fairly short time, when raw sludge feed can be resumed. Presumably, by then, the actual cause of the upset would be known and remedied.

The quantity of secondary sludge returned to the primary digester should be about 5-10% of the primary digester volume per day. Secondary sludge is an excellent source of acclimatized bacteria and alkalinity.

OBJECTIVES:

The trainee will be able to:

1. Recall the composition of a typical digester gas.
2. Name and state the purpose for the various components of a typical gas collection system.
3. Recall the digester to air mixture ratio which is explosive.
4. List the locations where flame arrestors should be installed.
5. Recall the maintenance requirements for:
    a. Steel gas piping
    b. Pressure Relief & Vacuum Relief valves
    c. Flame Arrestors
    d. Thermal Valves
    e. Sediment traps
    f. Drip Traps
    g. Pressure regulators
6. State the purpose of the sampling well.

GAS COLLECTION SYSTEM

General

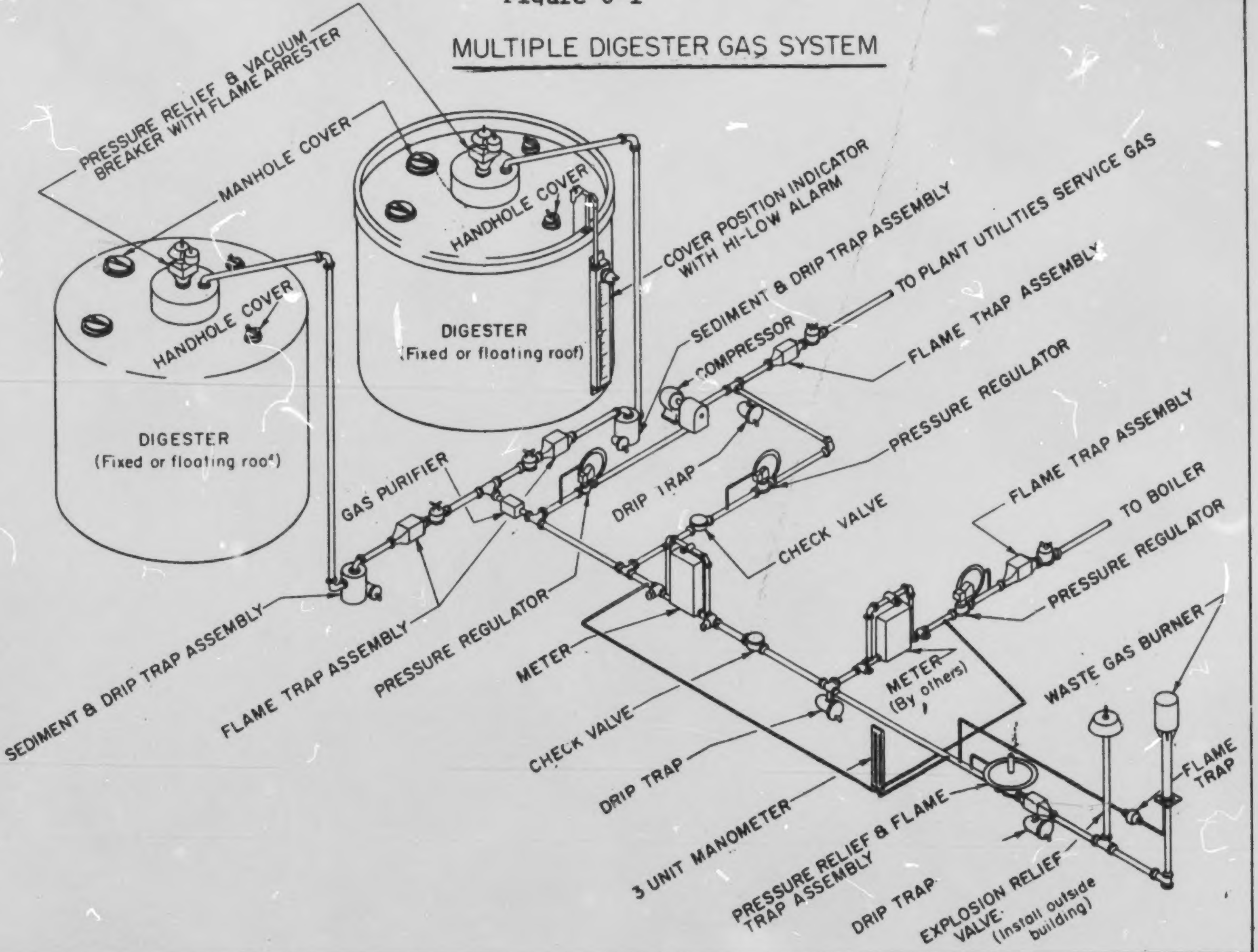
Digester gas usually contains 60-75% methane (CH_4), the balance being carbon dioxide (CO_2) with perhaps traces of nitrogen (N_2) and hydrogen sulphide (H_2S) being present. The gas, being formed in a warm, aqueous environment, is saturated with water vapour, some of which is removed in accumulators and drip traps before being fed to the boiler as fuel. The purpose of moisture removal is to prevent condensation occurring in gas meters, manometers, flame arresters and boiler gas metering equipment with attendant corrosion and/or plugging problems. While the efficiency of the moisture removal equipment is not particularly high, it is all that is available or installed at the present time and every effort should be made to ensure that it is operating as well as possible.

Also located throughout the gas piping system are flame arrester boxes, or "flame traps". These serve the purpose of preventing a flame travelling back along the system to the digester with a resultant explosion. See Figure 6-1.

In addition to flame arresters for anti-explosion or fire control, gas lines usually have at least one thermal valve installed. The thermal valve is spring loaded and maintained in an open position by a plug of wax. Should a flame manage to pass through the flame arresters and travel back upstream as far as the thermal valve, the plug of heavy wax melts in the heat and allows the pretentioned spring to close the valve, and seal the gas system.

Figure 6-1

MULTIPLE DIGESTER GAS SYSTEM


PRESSURE RELIEF & VACUUM BREAKER WITH FLAME ARRESTER
MANHOLE COVER
HANDHOLE COVER
HANDHOLE COVER
DIGESTER (Fixed or floating roof)
DIGESTER (Fixed or floating roof)
COVER POSITION INDICATOR WITH HI-LOW ALARM
SEDIMENT & DRIP TRAP ASSEMBLY
TO PLANT UTILITIES SERVICE GAS
COMPRESSOR
FLAME TRAP ASSEMBLY
PRESSURE REGULATOR
FLAME TRAP ASSEMBLY
TO BOILER
PRESSURE REGULATOR
GAS PURIFIER
DRIP TRAP
CHECK VALVE
WASTE GAS BURNER
FLAME TRAP
METER (By others)
SEDIMENT & DRIP TRAP ASSEMBLY
FLAME TRAP ASSEMBLY
PRESSURE REGULATOR
METER
CHECK VALVE
DRIP TRAP
3 UNIT MANOMETER
PRESSURE RELIEF & FLAME TRAP ASSEMBLY
DRIP TRAP
EXPLOSION RELIEF VALVE (Install outside building)

Other equipment pertinent to the gas collection system include the pressure regulator and the manometers and meters. The pressure regulator is a spring-loaded automatic valve, operated by pressure on a diaphragm which can be pre-set to maintain a given gas pressure in the digesters. If the digester gas pressure is greater than the pressure set at the regulator, the valve opens and allows the gas to flow to the boiler or the waste gas burner. If the digester gas pressure is lower than the setting, the valve closes and seals the entire system until gas production increases. At this time, no gas will flow to the waste gas burner or the boiler.

On the roofs of the digesters there is a pressure-vacuum relief valve (PRV). This valve is installed to prevent damage to the roof by excessive pressure or vacuum. For example, should it be necessary to perform maintenance upon flame arresters, meters, or other gas equipment, a plug valve may be closed upstream to isolate the section under maintenance or repair. The gas produced constantly in the digester then has nowhere to go and exerts pressure on the digester roof. The PRV, usually set to open at around 15 inches of water column, will open when the roof pressure reaches this level and vent the gas to the atmosphere for the duration of the maintenance period.

The operator should assiduously study plant drawings and manufacturer's specifications and thoroughly familiarize himself with the gas collection system and all the equipment associated with gas handling. Maintenance should be performed regularly. In installations where steel gas piping is used, sections of the piping from various locations should be removed every six months or so and inspected for corrosion. In all cases of valve or piping joints being disturbed, the system should be pressure tested for leaks in the presence of a safety officer, following prescribed testing procedures.

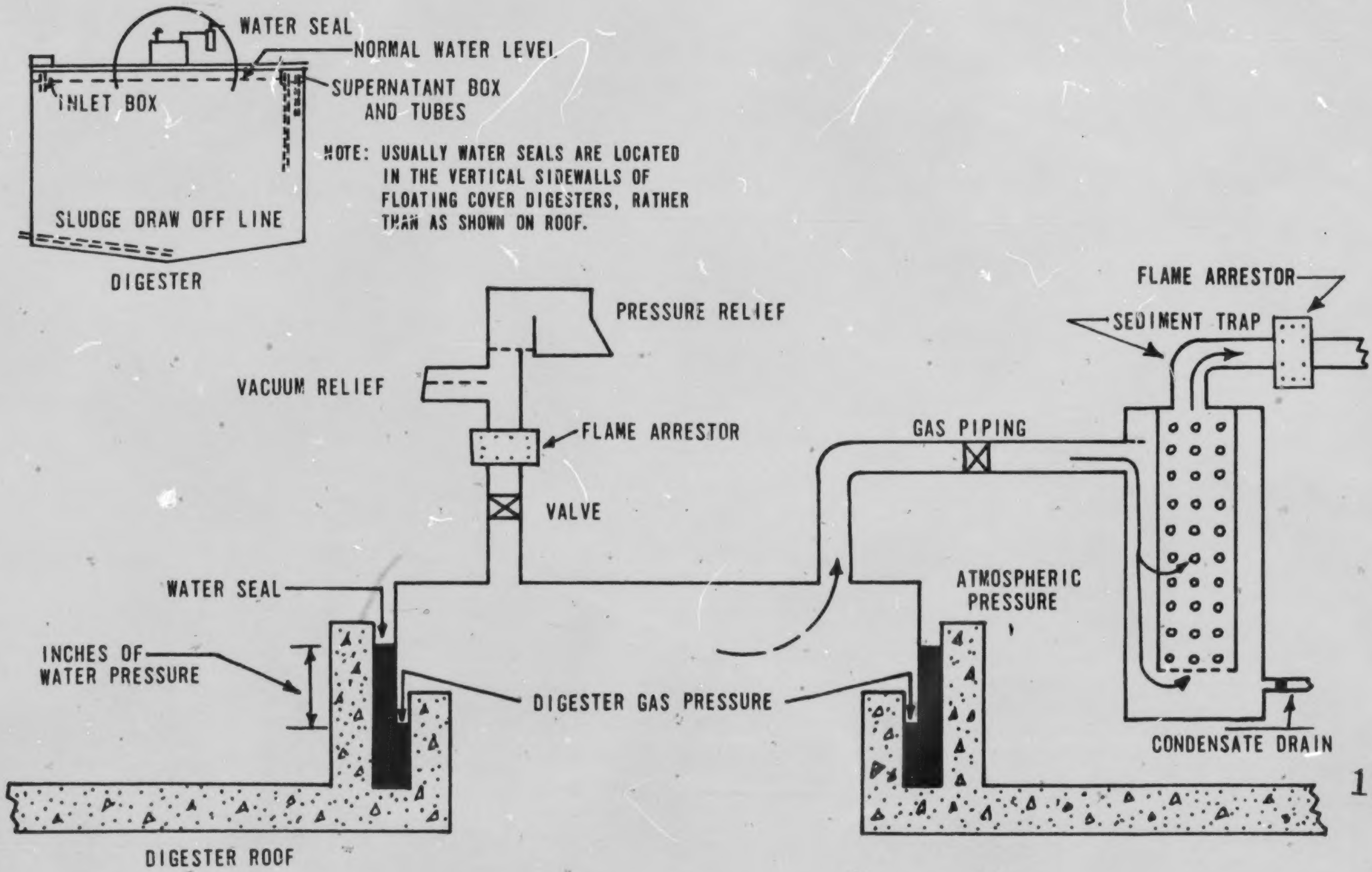

WATER SEAL
NORMAL WATER LEVEL
INLET BOX
SUPERNATANT BOX AND TUBES
NOTE: USUALLY WATER SEALS ARE LOCATED IN THE VERTICAL SIDEWALLS OF FLOATING COVER DIGESTERS, RATHER THAN AS SHOWN ON ROOF.
SLUDGE DRAW OFF LINE
DIGESTER
PRESSURE RELIEF
VACUUM RELIEF
FLAME ARRESTOR
VALVE
WATER SEAL
INCHES OF WATER PRESSURE
DIGESTER GAS PRESSURE
DIGESTER ROOF
GAS PIPING
ATMOSPHERIC PRESSURE
FLAME ARRESTOR
SEDIMENT TRAP
CONDENSATE DRAIN

Figure 6-2 Water Seal on Digester

It cannot be over-emphasized that digester gas is potentially highly dangerous, with respect to fire and explosion. However, a healthy respect allied with common sense and obeyance of safety regulations renders gas handling no more dangerous than any other plant operation.

Gas Dome

This is a point in the digester roof where the gas from the tank is removed. On fixed cover tanks there may also be a water seal (Fig. 6.2) incorporated to protect the tank structurally from excess positive pressure, or vacuum created by withdrawal of sludge or gas too rapidly.

If gas pressure is allowed to build up to 11 inches of water column pressure, it will escape around the water seal to the atmosphere without lifting the roof. If sludge is drawn or gas used too rapidly, the vacuum could exceed eight inches and break the water seal, thus allowing air to enter the tank. Without the water seal, the vacuum could become great enough to collapse the tank. Air in the tank creates an explosive condition. In addition, sulphuric acid corrosion is often found where air is consistently in contact with the gas. The pipeline between the gas storage tank and the digester will protect the digester from water seal leaks, if the line is clear. When liquids are pumped into the digester, gas can go out the line to the storage tank and when liquids are pumped out of the digester, gas can return through the line.

Pressure Relief and Vacuum Relief Valves

The pressure relief valve and the vacuum relief valve both are attached to a common pipe, (see Figure 6-3) but each works independently. The pressure relief valve is

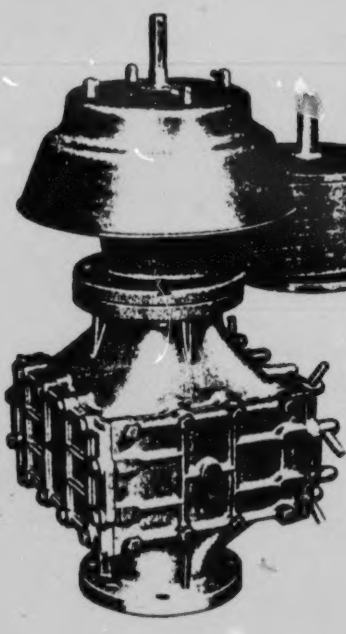


Figure 6-3 Pressure Relief and Vacuum Relief Valve

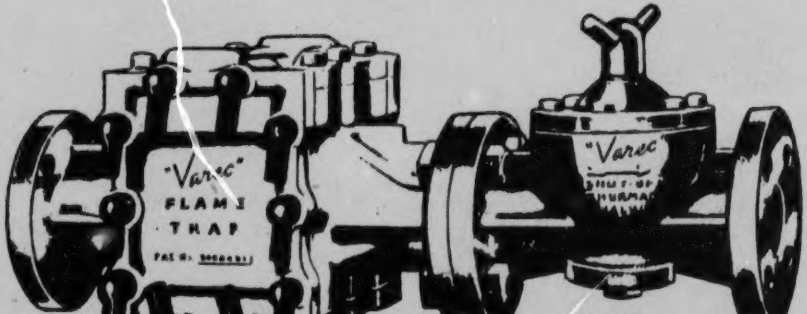

"Varec"
FLAME
TRAP
"Varec"

Figure 6-4 Flame Trap Assembly

(Flame Arrestor and Thermal Valve)

equipped with a seat and weighted with lead washer weights. Each weight is stamped with its equivalent water column height such as 1" H_2O or 3" H_2O. There should be sufficient weights, combined with the weight of the pallet, to equal the designed holding pressure of the tank. The gas pressure is normally established between six inches and eight inches of water. If the gas pressure in the tank exceeds the pop-off setting, then the valve will open and vent to the atmosphere for a couple of minutes, through the pressure relief valve. This should occur before the water seal blows out. The water seal can be broken when a tank is overpumped or gas removal is too slow.

The vacuum relief valve operates similary to the pressure relief valve except that it relieves negative pressures to prevent the tank from collapsing. Operating of either one of these valves is undesirable, because this allows the mixing of digester gas with air and can create an explosion outside the tank if the pressure relief valve opens and inside the tank if the vacuum relief opens.

WARNING

A gas mixture ratio of 5.7 to 13.5% digester gas to air is EXPLOSIVE (lower and upper limits).

These two valves should be checked at least every six months for proper operation.

On some occasions when digested sludge is being trucked away, it is not always possible to maintain gas pressure in the digesters and a slight vacuum may be exerted on the roofs. At these times the PRV again opens, admitting some air to equalize pressures and avoid roof damage. In some older digesters, occasionally there are manual valves installed upstream of the PRV. This is a design defect as it is potentially very dangerous should the manual valve be left closed by oversight. Where these valves are installed, they should be kept open at all times or better still, be removed from the system.

Flame Arrestors

A typical flame arrestor is a rectangular box holding approximately 50 to 100 corrugated aluminum plates with punched holes. If a flame should develop in the gas line, it would be cooled below the ignition point as it attempted to pass through the baffles, but gas could flow through with little loss in pressure. See Figure 6-4.

To prevent explosions, flame arrestors should be installed:

1. *Between vacuum and pressure relief valves and the digester dome.*

2. *After sidment trap on gas line from digester.*

3. *At waste gas burner.*

4. *Before every boiler, furnace, or flame.*

Flame arrestors should be services every three months by valving the gas off, pulling one end plate, and sliding the baffle cartridge out of the housing. A build-up of scale, salts from condensate, and residue build-up on the plates restricts gas flow.

The cartridge in the flame arrestor is designed to slide open so the baffles may be separated and washed without complete dismantling. When the unit is reassembled it should be tested for leaks by swabbing a soapsuds solution over potential leaky areas and inspecting for bubbles.

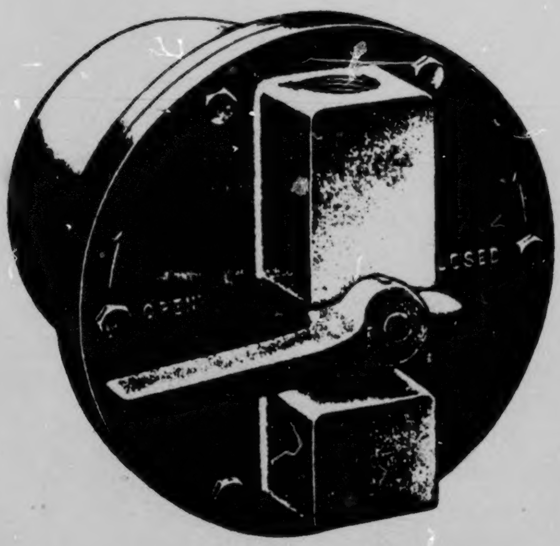


Figure 6-5 Drip Trap

ROTATING DISC TYPE

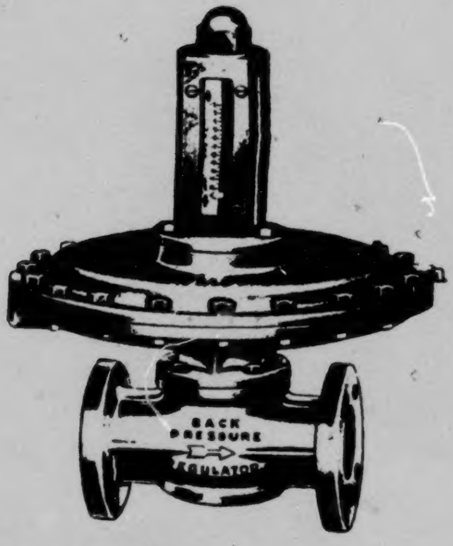

BACK
PRESSURE
REGULATOR

Figure 6-6 Pressure Regulator

Thermal Valves

Another protective device installed near a flame source and near the gas dome is the thermal valve. See Figure 6-4. This valve is round, with a weighted seat attached to a stem. The stem sets on a fusible disk holding the seat up. If enough heat is generated by a flame, the fusible element melts and drops the stem and valve seat to cut off gas flow. Most valves are equipped with a wing nut on top of the valve body. If the wing nut is removed, it uncovers a glass tube which shows visually if the stem is up. If the stem cannot be seen, then the valve is closed, and no gas can flow. If this occurs, the valve is removed and heated in boiling water to remove the melted fusible slug. A new slug is installed (slightly larger than an aspirin tablet), the stem replaced on top of it, and the valve is ready for service. These valves should be dismantled at least once a year in order to be positive that the stem is free to fall and not gummed up with residue or scale from the gas.

Sediment Traps

A sediment trap is a tank 12 to 15 inches in diameter and two to three feet in length. See Figure 6-2. It is usually located on top of the digester near the gas dome. The inlet gas line is near the top of the tank and on the side. The outlet line comes directly from the top of the sediment tank. The sediment trap is also equipped with a perforated inner baffle, and a condensate drain near the bottom. The gas enters the side at the top of the tank, passes down and through the baffle, then up and out the top. Moisture is collected from the gas in the trap, and any large pieces of scale are trapped before entering the gas system. The trap should be drained of condensate frequently but may have to be drained twice a day during cold weather, because greater amounts of water will be condensed.

Drip Traps - Accumulators

Digester gas is quite wet and in traveling from the heated tank to a cooler temperature the water condenses. The water must be trapped at low points in the system and removed, or it will impede gas flow and cause damage to equipment, such as compressors, and interfere with gas utilization. Traps are usually constructed to have a storage space of one to two quarts of water. All drip traps on gas lines should be located in the open air and be of the manual operation type. Traps should be drained at least twice a day and possibly more often in cold weather. Automatic drip traps are not recommended because many automatic traps are equipped with a float and needle valve orifice and corrosion, sediment, or scale in the gas system can keep the needle from seating. The resulting leaks may create gas concentrations with a potential hazard to life and equipment. See Figure 6-5.

The accumulators are simply large drums installed in the piping system, which allow the gas to expand momentarily before continuing to flow downstream. When the gas is allowed to expand, or reduce pressure, some cooling is achieved. This helps the moisture in the gas to condense to the liquid phase and allows collection of this condensate in the accumulator.

Gas Meters

Gas meters may be of various types, such as bellows, diaphragm, shunt flow, propeller, and orifice plate or differential pressure.

Gas meters should be read at the same time daily, and the readings recorded in a log. The difference between two successive readings then shows the daily gas production rate wich must be known if the digester performance is to be shown as cubic feet of gas produced per pount of volatile solids destroyed. The latter index of digester performance is usually 10-20 cu.ft/lb. volatile solids destroyed.

Little maintenance of meters is required except for occasional draining of condensate which, despite accumulators and drip traps located upstream, still tends to collect in meters.

Manometers

Various manometers are usually installed in the gas piping system. Normally, these are installed on the digester gas line, the service line to the boiler, and the line to the waste gas burner. The manometers are normally oil filled and read pressure in inches of water column. Readings should be noted and recorded daily. The manometer readings are useful in showing what is occurring in the gas system. For example, if the pressure regulator is set for 10 inches of water column, and the digester gas line, which monitors the pressure in the roof of the digester, shows 5 inches, then the regulator valve will be closed and the service line and waste gas line manometers will read zero. When the digester gas line manometer pressure is greater than the pre-set 10 inches, the regulator valve will open and the waste gas line and service line manometers will then show pressure readings, indicating the gas is flowing to these places.

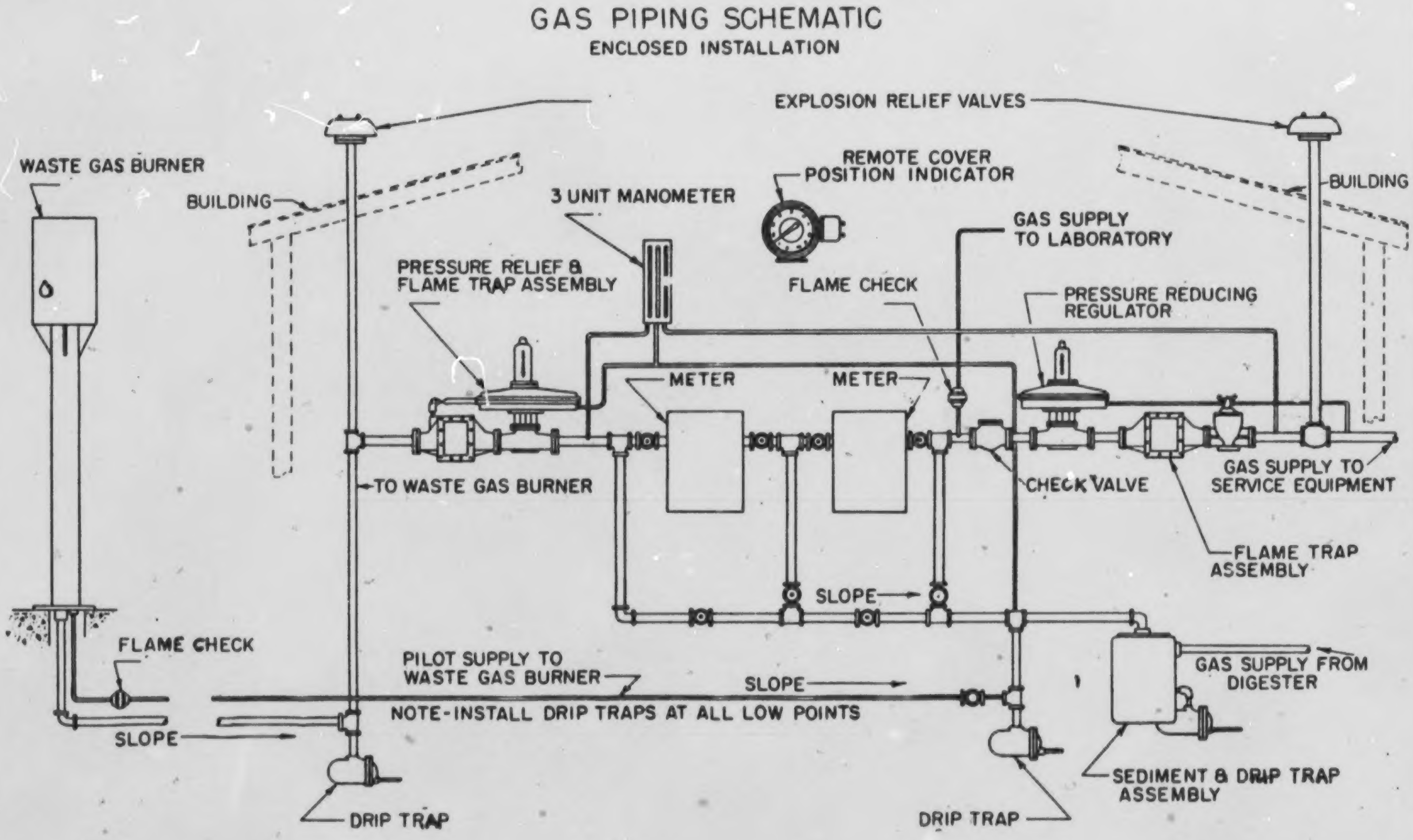
Pressure Regulators

Pressure regulators (Figure 6-6) are typically installed next to and before the waste gas burner. Such regulators are usually of the diaphragm type and control the gas pressure on the whole digester gas system. They are normally set at eight inches of water column by adjusting the spring tension on the diaphragm. Whenever an adjustment of a pressure setting is made, check the gas system pressure with a manometer for the proper range. If the gas pressure in the system is below eight inches of water column, no gas flows to the waste burner. When the gas pressure reaches eight inches of water column, the regulator opens slightly, allowing gas to flow to the burner. If the pressure continues to increase, the regulator opens further to compensate. The only maintenance this unit requires is on the thermal valve on the discharge side which protects the system from back flashes. This unit is spring loaded and controlled by a fusible element that vents one side of the diaphragm, thus stopping the gas flow when heated. Maintenance includes checking for proper operation of the regulator and of the fusible element. Gas regulators are also placed at various points in the system to regulate the gas pressure to boilers, heaters, and engines. Diaphragm conditions in the regulators should be checked at periodic intervals.

Waste Gas Burner

Waste gas burners are used to burn the excess gas from the digestion system. The waste gas burner is equipped with a continuous burning pilot flame, so that any excess gas will pass through the gas regulator and be burned. The pilot flame should be checked daily to be sure that it has not been blown out by wind. If the pilot is out, gas will be vented to the atmosphere creating an odorous and potentially explosive condition. (See Figure 6-7)

Figure 6-7 Waste Gas Burner


GAS PIPING SCHEMATIC
ENCLOSED INSTALLATION
EXPLOSION RELIEF VALVES
WASTE GAS BURNER
BUILDING
BUILDING
REMOTE COVER POSITION INDICATOR
3 UNIT MANOMETER
GAS SUPPLY TO LABORATORY
PRESSURE RELIEF & FLAME TRAP ASSEMBLY
FLAME CHECK
PRESSURE REDUCING REGULATOR
METER
METER
TO WASTE GAS BURNER
CHECK VALVE
GAS SUPPLY TO SERVICE EQUIPMENT
FLAME TRAP ASSEMBLY
SLOPE
FLAME CHECK
PILOT SUPPLY TO WASTE GAS BURNER
SLOPE
GAS SUPPLY FROM DIGESTER
NOTE-INSTALL DRIP TRAPS AT ALL LOW POINTS
SLOPE
SEDIMENT & DRIP TRAP ASSEMBLY
DRIP TRAP
DRIP TRAP

Sampling Well (Thief Hole)

The sampling well consists of a 3- or 4-inch pipe (with a hinged seal cap) that goes into the digestion tank, through the gas zone, and is always submerged a foot or so into the digester sludge. This permits the sampling of the digester sludge without loss of digester gas pressure, or the creation of dangerous conditions caused by the mixing, or the creation of dangerous conditions caused by the mixing of air and digester gas. However, caution must be used not to breathe gas which will always be present in the sample well and will be released when first opened. A sampling well is sometimes referred to as a "thief hole".

SUBJECT:

DIGESTER OPERATION

TOPIC: 7

STARTUP, SHUTDOWN & CLEANING

OBJECTIVES:

The trainee will be able to:

1. Apply proper procedures for digester startup and shutdown.
2. Recall the major safety factors during startup and shutdown operations.
3. Discuss in general terms the procedure for cleaning a digester.

START-UP SHUTDOWN AND CLEANING

START-UP

When wastewater solids are first added to a new digester, naturally occurring bacteria attack the most easily digestible food available, such as sugar, starches, and soluble nitrogen. The anaerobic acid producers change these foods into organic acids, alcohols, and carbon dioxide, along with some hydrogen sulfide. The pH of the sludge drops from 7.0 to about 6.0 or lower. An "acid regression stage" then starts and lasts as long as six to eight weeks. During this time ammonia and bicarbonate compounds are formed, and pH gradually increased to around 6.8 again, establishing an environment for the methane fermentation or alkaline fermentation phase. Organic acids are available to feed the methane fermenters. Large quantities of methane gas are produced as well as carbon dioxide, and pH increases to 7.0 to 7.2. Once alkaline fermentation is well established, strive to keep the digesting sludge in the 7.0 ro 7.2 pH range. If too much raw sludge is added to the digester, the acid fermenters will predmoninate, driving the pH down and creating an undesirable condition for the methane fermenters.

The first group of organisms must do its part before food is available to the next group. Once the balance is upset, so is the food cycle to the next group. When the tank reaches the methane fermentation phase, there is sufficient alkaline material to buffer the acid stage and maintain the process. Operational actions such as poor mixing, addition of excess food, excess water supplied to dilute the alkaline buffer, over-drawing digested sludge, or improper temperature changes can cause souring again.

The simplest way to start a digester is with seed sludge (actively digesting material) from another digester. The amount of seed to use is dependent upon factors such as mixing processes, digester sizes, and sludge characteristics, but amounts between 10 and 50% of the digester capacity have been used.

START-UP PROCEDURE FOR FIRST STAGE DIGESTER

1. Inspect the inside of the digester as follows:

   (a) Verify by observation that the inside of the digester is free of tools, ladders, or any extraneous debris. (Do not enter digester until forced-air ventilation has been provided, and oxygen deficiency tests and explosive atmosphere tests have been run.)

   (b) Verify by observation that all internal piping joints are tight, piping is in place and securely fastened at the support points, and that all bolts are tight.

   (c) Look into or run air or water through all piping to verify that all lines are open. WHY? Once the digester is full of liquid, the inside piping will be inaccessible.

   (d) Verify by observation that all personnel are clear of the unit and are aware of the start-up.

2. Inspect the outside of the digester as follows:

   (a) Verify by observation that all piping joints are tight, piping is in place and securely fastened at the support points, and that all bolts are tight.

   (b) Run air or water through all piping to verify that all lines are open.

   (c) Manually turn all valves to make sure that they turn freely. WHY? If there are valve or piping malfunctions once the digester is full of liquid, it would be necessary to drain the digester to do repair work.

3. Inspect all components of the digester external equipment for power available, piping clean and solidly anchored, valves properly positioned, couplings tight and aligned, pumps packed and water flow to packing. Inspect by observation all external power switches to assure that all motors are tagged and physically padlocked. Manually turn motor-control switch to OFF, padlock electrical power supply switches in OFF position, and place red LOCK-OUT-TAG on power box for switch before performing any work on the component. External components are raw sludge pump, coupling and motor, hot water recirculation pump, coupling and motor, sludge recirculation pump, motor and coupling, compressor and drive, gas meter, gas manometer, water traps, regulators, pressure and vacuum relieve valves, flame arresters, sludge flow meters and density meter. WHY? Once the digester is in operation, a malfunction of certain pieces of external equipment will impede or stop the digester operation.

4. Fill the digester with raw sewage to the normal operating level as determined by the supernatant overflow.

   (a) Manually open the raw sewage inlet valve to the raw sludge pump suction.

   (b) Manually open the discharge valve from the raw sludge pump to the digester.

   (c) Remove red LOCK-OUT-TAG, unlock electrical power supply switch and turn it to ON, manually turn raw sludge pump motor-control switch to ON(HAND) to verify component is operational. Turn switch to AUTO.

   (d) Stop the raw sludge pump when the raw sewage begins to flow out the supernatant line.

(e) Visually inspect for liquid leaks.

(f) Use raw sewage instead of raw sludge to fill the digester.
WHY?

   (1) Raw sludge will cause the digester to immediately go into an overloaded state.
   (2) Raw sewage is easier to handle in case the digester had to be drained right away for repair work.

5. Seal all digester openings (by closing valves, covering hatches with bolted covers, etc.) including gas lines, pressure relieve vent, inspection manholes, supernatant lines, raw sludge feed lines, digested sludge draw-off lines, and sludge recirculating lines.

6. Using a water-column pressure indicator, slowly pressurize the digester gas dome to 15-18 inches (check design data) of water column using compressed air as follows:

(a) Paint joints and gasket seals with a soapy solution and look for soap bubbles to determine whether there are leaks.

(b) Verify by observation that the digester maintains a minimum time static pressure loss as specified by the design data.

(c) Use water column pressure indicator to verify that the digester gas pressure relief vent will open at 15 inches (verify by design data) of water column. WHY? Digester gas leaks could cause explosion/fire hazard.

7. Unseal all digester openings necessary for normal operation including the raw sludge lines, pressure relief vent, gas lines, supernatant lines, and sludge recirculation lines. Reconnect any lines that had been disconnected during the sealing process when hunting for gas leaks.

8. Fill the gas manometer with water to the "zero" level mark.

9. Manually open the inlet and outlet valves to the digester recirculating sludge pump.

10. Remove red LOCK-OUT-TAG, unlock electrical power supply switches of exchange hot water recirculating pump, digester recirculating sludge pump, and heat exchanger burner control.

11. Manually turn on the heat exchanger hot water recirculation pump and the digester recirculating sludge pump.

12. Manually turn on the heat exchanger burner control. Verify by observation that the digester gas valve is closed and the auxiliary fuel valve is open. WHY? There won't be enough digester gas available from the secondary digester to burn in the heat exchanger.

13. Continue to heat the digester raw sewage until the recirculating sludge inlet temperature is 90^{O}F. (Check PROCESS CONTROL INSTRUCTIONS for exact temperature.)

14. Start adding raw sludge to the digester at the appropriate rate of 0.4% of the digester liquid contents per day.

15. If required, maintain the digester recirculating sludge pH within the 6.8-7.2 range by adding powdered lime as follows:

(a) Mix the lime with water before adding it to the digester. A sump pump in a barrel discharging back into the barrel makes a suitable mixing device.

(b) The amount of lime needed is directly proportional to the amount of raw sludge added per day.

16. Add seed sludge to the digester in the amount of 5-10% of the digester capacity if seed sludge is available either from the secondary digester or hauled in by truck from a nearby digester.

17. Follow process control instructions while bringing the digester into operation.

18. Light the waste gas burner as soon as the digester gas is of burnable quality.

19. When the digester gas production is of sufficient quantity and quality (40% CO_2) to burn in the heat exchanger, switch from auxiliary fuel to digester gas fuel as follows:

    (a) Purge gas line to heat exchanger burner by venting out the burner stack before trying to ignite the burner.

MAJOR SAFETY FACTORS

(a) Do not enter digester until forced-air ventilation has been provided and oxygen deficiency tests and explosive atmosphere tests have been run. WHY? Explosive, toxic, poisonous, and suffocating gases are present in all digesters and can cause sickness or death to operator.

SHUT-DOWN PROCEDURE FOR FIRST STAGE DIGESTER

1. Allow no smoking or open flames in digester areas.

2. Manually shut off power to gas mixer drive motor, the heat exchanger and circulating pump. Place red LOCK-OUT-TAG on power box for switch before performing any work on the component. This should be done at least 24 hours before digester draining procedures begin.

3. Change raw sludge feed to secondary digester.

4. Withdraw all digested sludge to digested sludge handling unit (drying beds, vacuum filter, centrifuge) by opening bottom draw-off valve from primary digester and routing sludge through appropriate valving to component.

5. Using a digester circulating pump, transfer primary digester solids to the secondary digester by lining up valving from a low primary (not bottom) circulating valve to the secondary digester.

6. In the digester which is equippped with a side access cover, when the level of sludge is below the side wall access point, remove side access covers by unbolting to provide ventilation and better inspection of the bottom materials. Allow no smoking or open flames within 30 feet of the open port. Do not enter the digester until provision has been made for high volume, forced air ventilation.

7. If a sand build-up in the bottom of the digester is evident, transfer only as much sludge to the secondary digester as possible without also transferring sand.

8. Hose down with fire hose all interior surfaces, piping, etc.

9. When personnel are ready to enter the digester, provide, in addition to ventilation, safety harnesses and lines tended by a man watching from the access port. If a ladder is used, tie a line to its top rung and secure the line firmly outside the digester. If an extension ladder is used, extend ladder to length needed and tie overlapping rung areas securely to prevent loss of lower section in digester. Allow no sludge to splash in eyes, ears, nose, or mouth.

10. Make provisions for removal and disposal of sand and proceed until digester is empty.

11. Finish hose down of digester interior. Pull off all hanging strings of rags from pipings, pipe hangers, and brackets.

12. Visually inspect all interior piping, hangers, supports, and footings for signs of failure or deterioration. Record all findings for reference at future inspections. Repair or replace any equipment showing indications of advanced deterioration. (Use caution when dismantling digester piping.)

MAJOR SAFETY FACTORS

(a) Allow no smoking or open flames in digester area.

(b) Allow no sludge to splash in eyes, ears, nose or mouth. Flush areas with fresh water if sludge is accidentally splashed on body.

(c) Use caution when **dismantling** digester piping.
WHY? Iron sulfide oxidizes rapidly on contact with atmospheric oxygen causing possible heat or flame which could injure or kill operator.

START-UP PROCEDURE FOR SECOND STAGE DIGESTER

1. Allow no smoking or open flames in the digester area.

2. Inspect the inside of the digester as follows:

   (a) Provide adequate ventilation in all areas.
   (b) Verify by observation that the inside of the digester is free of tools, ladders, or any extraneous debris.
   (c) Verify by observation that all internal piping joints are tights, piping is in place and securely fastened at the support points, and that all bolts are tight.
   (d) Look into or run air or water through all piping to verify that all lines are open.
   WHY: once the digester is full of liquid, the inside piping will inaccessible.
   (e) Verify by observation that all personnel are clear of the unit and are aware of the start-up.
   WHY: to prevent injury to personnel.

3. Inspect the outside of the digester as follows:

   (a) Verify by observation that all piping joints are tight, piping is in place and securely fastened at the support points, and that all bolts are tight.
   (b) Run air or water through all piping to verify that all lines are open.
   (c) Manually turn all valves to verify that they turn freely.
   WHY: if there are valve or piping malfunctions once the digester is full of liquid, it would be necessary to drain the digester to repair work.

4. Inspect all components of the digester external equipment for power available (indicating lights on (power)), piping clean and solidly anchored, valves properly positioned (valves not in backwards), couplings tight and aligned, pumps packed and water flow to packing. External components are digested sludge pump, variable speed drive and motor, piping and valves, gas meter, gas manometers, gas water traps, gas pressure and vacuum relief valves, flame arrestors, floating cover, gas compressor, gas storage tanks.
WHY: once the digester is in operation, a malfunction of certain pieces of external equipment will impede or stop the digester operation.

5. Fill the digester with raw sewage to the normal operating level.

   (a) Manually open the raw sewage inlet to the raw sludge pump suction.
   (b) Manually open the discharge valve from the raw sludge pump to the digester.
   (c) Remove red LOCK-OUT-TAG, unlock electrical power supply switch and turn it to ON, manually turn raw sludge pump motor control switch to ON(HAND) to verify component is operational. Turn switch to AUTO.
   (d) Manually stop the raw sludge pump by turning the control switch to OFF when the raw sewage begins to flow out the supernatant line.
   (e) Visually inspect for liquid leaks. Repair any leaks found by referring to corrective maintenance. (Prevent sludge from splashing in the eyes, ears, nose or mouth).
   (f) Use raw sewage instead of raw sludge to fill the digester.
   WHY:
   (1) Raw sludge will cause the digester to immediately go into an overloaded state.
   (2) Raw sewage is easier to handle in case the digester had to be drained right away for repair work.

6. Seal as directed by plant operation manual all digester openings including gas lines, pressure relief vent, inspection manholes, supernatant lines, sludge feed lines, digested sludge draw-off lines.

7. Using a water column pressure indicator, slowly pressurize the digester gas dome to 15-18 inches (check design data) of water column using compressed air as follows:

    (a) Paint joints and gasket seals with a soapy solution and look for soap bubbles.
    (b) Verify by observation that the digester maintains a minimum time statis pressure loss as specified by the design data. If it does not, refer to corrective maintenance.
    (c) Use water column pressure indicator to verify that the digester gas pressure relief vent will open at 15 inches (verify by design data) of water column. WHY: digester gas leaks could cause an explosion/fire hazard.

8. Unseal all digester openings necessary for normal operation including: sludge lines, pressure relief vent, gas lines, and supernatant lines. Reconnect any lines that had been disconnected during the sealing process when hunting for gas leaks.

9. Fill (as directed by plant operation manual) the gas manometer with water to the "ZERO" level marks. Add a drop of red food coloring to each leg of the manometer to make level easier to see.

10. Valve primary supernatant overflow to secondary digester.

11. Allow digester gas dome to vent to the atmosphere through the pressure relief valve.

12. Follow process control's instructions while bringing the digester into normal operation.
13. When the gas production is 40 percent or less CO_2, purge the gas piping to the main gas header, then valve the secondary gas production into the main gas header.

MAJOR SAFETY FACTORS

1. Allow no smoking or open flames in the digester area.
   WHY: digester gases are flammable and/or explosive when ignited causing injury or death to operator.

2. Allow no sludge to splash in eyes, ears, nose or mouth. Flush area with fresh water if sludge is accidentally splashed on body.
   WHY: high bacterial content of sludge may cause disease to operator.

3. Provide adequate ventilation in all areas.
   WHY: digester gas can be poisonous in even small amounts to operator causing sickness or death.

SHUT-DOWN PROCEDURE FOR PROCESS

1. Allow no smoking or open flames in digester area.

2. Manually valve the primary digester supernatant flow so that it returns to the plant headworks. (This should be done at least 24 hours before digester draining procedures begin).
   WHY: to allow stratification of digester contents and to reduce gas production.

3. Withdraw all digested sludge to the digested sludge handling unit (drying beds, vacuum filter, centrifuge, and other components) by manually opening bottom draw-off valve from secondary digester and pumping with digested sludge pump through appropriate valving to unit.

4. When all the digested sludge has been withdraw, manually valve the bottom draw-off flow to return to the plant headworks.

5. When the digester cover is within 12" of the corbels, manually valve off the gas line from the gas dome and tag the valve "closed, do not open".

6. Manually open all the hatch covers in the floating cover and provide forced ventilation for the gas dome.

7. Continue to drain the secondary digester to the headworks until the scum blanket is reached.

8. Valve the bottom draw off of the digested sludge pump and pump the scum to the multiple hearth incinerator unit.
   WHY: scum will plug any further treatment unit except the incinerator.

9. When the level of sludge is below the side wall access port, using rocket wrench undo bolts and remove hatch cover to provide ventilation and better inspection of the bottom materials. Allow no smoking or open flames within 30 feet of the open port.

10. From the side wall access port, use high pressure hose to hose down all interior surfaces, piping, and other components. (Do not enter the digester until provisions (forced air ventilation fans and air hoses to ventilate digester interior) have been set up for high volume, forced air ventilation. Toxic or suffocating gases may overcome personnel if fresh air is not provided.)

11. When personnel are ready to enter the digester, provide, in addition to ventilation, safety harnesses and lines tended by a man watching from the access port. If a ladder is used, tie a line to its top rung and secure the line firmly outside the digester. If an extension ladder is used, extend ladder to length needed and tie overlapping rung areas securely to prevent loss of lower section in digester. (Allow no sludge to splash in eyes, ears, nose or mouth).

12. Using water to slurry bottom contents and a trash pump to remove the material and transport it to holding lagoons, remove, dispose and proceed until digester is empty. (This project can be undertaken by plant personnel or contracted to outside companies. Sand can be disposed of by burial, landfill or other means).

13. Finish hosedown of digester interior. Remove by hand all hanging strings of rags, and other debris from piping, pipe hangers and brackets.

14. Visually inspect all interior piping, hangers, supports, footings for signs of failure or deterioration. Record all findings for reference at future inspections. Repair or replace any equipment showing indications of advanced deterioration. (Use caution while dismantling digester piping).

15. For any components needing repair, manually turn motor control switch to OFF, padlock electrical power supply switch in OFF position, and place red LOCK-OUT-TAG on power box for switch.
WHY: to prevent automatic start-up or another person from starting motor which could cause damage to equipment.

MAJOR SAFETY FACTORS

1. Allow no smoking or open flames in digester area.
WHY: digester gases are flammable and/or explosive when ignited causing severe burns, injury and possible death to operator.

2. Allow no sludge to splash in eyes, ears, nose or mouth. Flush area with fresh water if accidentally splashed.
WHY: high bacterial content of sludge may cause disease of operator.

3. For any component needing repair, manually turn motor control switch to OFF, padlock electrical power supply switch in OFF position, and place red LOCK-OUT-TAG on power box for switch before performing any work on the component.
WHY: to prevent automatic start-up or another person from starting motor which could cause serious injury to operator.

4. Use caution while dismantling digester piping.
WHY: iron sulfide oxidizes rapidly on contact with atmospheric oxygen causing possible heat or flame which could injure operator.

5. Provide adequate ventilation in all areas.
WHY: to prevent sickness or death of operator due to build of gas.

DIGESTER CLEANING

Despite mixing equipment manufacturers' claim, all digesters sooner or later build up a bottom deposit of sand, grit, and heavy solids of all descriptions. Eventually, if allowed to progress, these deposits would effectively reduce the active digestion volume to the point where the process is affected. For this reason, every so often as dictated by operator experience, the digesters should be "taken down" completely and thoroughly cleaned.

Various procedures have been described for this operation including the introduction of high pressure inert gases such as nitrogen to the deposits to "fluidise" the solids and render them "pumpable", but the only really sure method is the time-honoured one of entering the digester and breaking up the deposits with a fine hose. The initial step is to cease all raw sludge additions to the digester and allow several days for the gas production to drop to almost zero. This indicates that the sludge already in the tank is more or less stabilised. The second step is to open all roof vents, hatches, etc. The gas piping should be backflushed from the waste gas burner right back to the digester roof with nitrogen and then all the valves closed off to avoid any residual digester gases entering the system.

During these operations, the digester contents should be trucked away. Ultimately, a point will be reached where the sludge pumps will not handle the heavy bottom sludges. At this time a large submersible pump should be lowered into the bottom deposits, and a ladder installed to allow personnel to enter the digester with a fire hose. All available safety apparatus should be employed at this time including a powerful vent fan, breathing apparatus, safety harness, gas analysers, and so on. A safety officer should be present to ensure that all current safety procedures and regulations are strictly adhered to. With the submersible pump or pumps running, the operator breaks up the bottom solids deposits with the powerful fire hose and flushes them to the pump which should discharge directly to a sludge haulage truck. The operation goes surprisingly quickly when all the necessary proper equipment is available. When the digester is empty and clean, all internal piping and equipment should be inspected and repaired, if necessary.

SUBJECT: TOPIC: 8

DIGESTER OPERATIONS AEROBIC SLUDGE DIGESTION

OBJECTIVES:

The trainee will be able to:

1. List the advantages of the aerobic digestion process over the anaerobic digestion process.
2. Describe the basic steps in the aerobic digestion process.
3. Recall the factors affecting the settleability of aerobically digested sludge.

AEROBIC SLUDGE DIGESTION

GENERAL

The use of aerobic digesters to treat water pollution control plant sludges prior to their ultimate disposal is relatively new in the Province of Ontario. The first aerobic digester in the Province has only been in operation for approximately eight years. The aerobic digestion process provides an alternative to the anaerobic digestion process and offers several advantages over anaerobic digestion. Anaerobic digestion requires relatively sophisticated process equipment and closely regulated process conditions in order to operate efficiently. The aerobic digestion process basically consists of aerating waste sludge in an unheated open tank. Minimal supervision is required because problems of process failure and hazardous operating conditions associated with the anaerobic digestion process do not exist. The aerobic digestion process is, therefore, especially applicable in smaller communities where costs of an anaerobic digestion system would be excessive.

The design criteria on which aerobic digesters have been based were derived from a number of laboratory studies. Hydraulic retention times of 10-15 days with air flow rates of 15-20 cfm/1000 ft^3 were recommended for design.

A survey was undertaken to determine the validity of these design parameters as well as to evaluate the performance of the aerobic digestion process and the mechanical designs employed. The aerobic digestion process at seven treatment plants in the Province of Ontario was evaluated over a period of approximately one year.

A summary of the physical plant data of the plants included in this study is presented in Table 8-1.

Aerobic Digester Operation

The operation of an aerobic digester consists of several basic steps, the time period between the steps varying at the different plants. Before sludge is wasted to the digester, the aeration device is shut off to allow the digesting sludge to settle. After a sufficient period of quiescence, normally between an hour to twenty-four hours, supernatant is removed and returned to the activated sludge process.

TABLE 8-1 - PHYSICAL PLANT DATA

PLANT	PLANT TYPE	PLANT FLOW		DIGESTER CAPACITY cu ft
		DESIGN mgd	ACTUAL mgd	
Penetang	Contact Stabilization	0.33	0.40	# 1 8,860 # 2 4,430
Bolton	Conventional	0.50	0.25	15,700
Aurora	Contact Stabilization	1.85	1.40	# 1 57,250 # 2 10,800
West Don	Conventional	0.33	0.37	9,700
Unionville	Conventional	0.40	0.03	# 1 11,540 # 2 6,060
Picton	Contact Stabilization	0.54	0.90	# 1 10,450 # 2 13,500
Kleinburg	Extended Aeration	0.05	0.03	1,370

The aeration device is turned on and sludge is wasted to the digester. Digested sludge removal is normally carried out after the settling period either before or after supernatant removal.

DISCUSSION

Results of routine sample analyses are presented in Tables 8-2 for the digester feed sludge, the digester sludge, and the digester supernatant, respectively. Because of the volume of data obtained in this study, the data are presented in such a way that the full range of operating conditions are represented. Consequently, for each analysis, the overall average, the range of plant averages, and the range of individual results are shown. The data were compiled from seven plants.

A summary of the process data including hydraulic and organic loading, sludge age, and air supply is presented in Table 8-3.

Digester Sludge Characteristics (Table 8-4)

Most of the digesters in this study normally operate at a TS concentration greater than 2 percent. At TS* concentrations greater than 3 percent, difficulties

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* TS - Total Solids

TABLE 8-2

CHARACTERISTICS OF DIGESTER FEED SLUDGES (mg/l)

Parameter	Overall Average	Range of Plant Averages	Range of Results
pH	6.7	6.3-7.0	5.5-7.4
COD	19,000	7,900-63,000	1,600-92,700
TS	20,200	8,550-41,600	1,960-86,600
TVS	11,500	5,210-29,200	870-63,000
Kjeldahl N	960	400-3,540	27-18,000
Total P	370	144-990	23-1,340

TABLE 8-3 - AEROBIC DIGESTION PROCESS

DIGESTER		HYDRAULIC RETENTION days	SLUDGE AGE days	LOADING DESIGN lbs VS/cu ft/day	LOADING ACTUAL lbs VS/cu ft/day	AIR SUPPLY DESIGN cfm/1,000 cu ft	AIR SUPPLY ACTUAL cfm/1,000 cu ft
Penetang	# 1	14	30	0.08	0.024	20	-
	# 2	-	-	(overall)	-	20	-
Bolton		30	29	0.0256	0.025	25	19
Aurora	# 1	-	-	0.024	-	23	23
	# 2	20	30	(overall)	0.025	8.4	8.4
West Don		60	45	0.05	0.027	25	46
Unionville	# 1	360	320	0.0166	0.0035	30	-
	# 2	-	-	(overall)	-	(both)	-
Picton	# 1	65	45	0.0326	0.012	19	-
	# 2	-	-	(overall)	-	(both)	-
Kleinburg		60	100	0.024	0.020	29	29

with sludge settling and supernatant removal are frequently encountered. With a two-stage system, the first stage can be operated at a solids concentration low enough to minimize these problems, while the second stage can be used for sludge concentration and final stabilization. Supernatant removal is required less frequently in the second stage of digestion (weekly rather than daily) so that longer settling times (as long as 1 day) can be utilized.

One necessary condition for the effective operation of an aerobic digester is the formation of a settleable sludge. The advantages of good settleability include minimization of the ultimate disposal costs by the production of a concentrated sludge, the production of a high quality supernatant, and the minimization of the amount of time digesting sludge is subjected to anaerobic conditions.

Settleability of aerobically digesting sludges is dependent on solids concentration, DO, and the type of sludge fed to the digester. It seems that with long retention times, settleability of the sludge and supernatant quality deteriorate. Poor settleability has also been observed when residual DO levels are low (less than 1 mg/l DO). Low DO concentrations have been encountered most frequently in digesters receiving primary sludge.

Volatile Solids Reductions

The VS reductions in aerobic digesters have normally ranged from 10 to 25 percent in first-stage or single-stage units and up to a maximum of about 45 - 50 percent in two-stage digesters. In some cases, the VS fraction has not decreased, while in other instances it has increased. This is probably because of periodic fluctuations in the volatile fraction of the waste sludge. Only a complete mass balance on the system would show consistent reductions.

The type of sludge wasted to the digester should also be considered. The same percentage reduction in VS should not be expected with waste activated sludge from an extended aeration plant as that achieved in digesting primary sludge because of the different initial sludge ages. The performance of an aerobic digester, therefore, cannot be judged on the basis of VS reduction. The only possible exception is a batch digestion, which under practical operating conditions is never encountered. The necessary sampling programme for digester control by a mass balance on the volatile matter would be impractical for the size of plant that would be using an aerobic digester.

TABLE 8-4

CHARACTERISTICS OF DIGESTER SLUDGES (mg/l)

Parameter	Overall Average	Range of Plant Averages	Range of Results
pH	6.8	6.2-6.7	5.4-8.4
COD	20,800	14,100-33,200	1,900-51,000
TS	27,600	13,600-39,400	4,040-59,800
TVS	14,400	9,500-21,500	1,940-36,000
Kjeldahl N	1,050	640-1,460	25-4,100
Total P	510	325-900	10-1,500
Soluble P	35	1.3-70	0.6-113

Supernatant Characteristics

Apart from the stability and concentration of digesting sludge, the next most important aspect of aerobic digestion is the production of a low-strength superantant to minimize any additional load on the activated sludge process. Because the daily flow of supernatant returned to the plant is normally about 1 percent of the total plant flow, the organic load of the supernatant will be insignificant if the organic strength of the supernatant is equivalent to that of the raw wastewater. A high solids concentration in the supernatant does not necessarily indicate a high load to the aeration tanks. The true loading resulting from the supernatant is represented by the soluble BOD (or filtered BOD) which, **as may be seen in Table 8-5**, is equal to or less than the organic strength of raw wastewater. The loading caused by SS in the supernatant will not have the same effect on the plant as a similar concentration from an anaerobic digester. This is because the solids from the aerobic digester are in an endogenous stage of respiration with a lower specific oxygen uptake rate than the activated sludge solids. The solids in an anaerobic digester supernatant are in a reduced state and, therefore, represent a greater organic load to an oxidizing environment. While the organic load resulting from SS* in an aerobic digester supernatant is expected to be considerably less than a corresponding SS concentration for an anaerobic digester, a high solids concentration in the supernatant nevertheless represents an inefficiency in the process.

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* SS - Suspended Solids

While the concentrations of Kjeldahl nitrogen and soluble phosphorus are higher in digester supernatant than in raw wastewater, the concentration factor is usually five times or less; and, therefore, the total weight of nutrients that can be removed from aerobic digester supernatant is only a small fraction of the total plant nutrient flow. Aerobic digester supernatant in most installations affords the opportunity of nitrogen removal by denitrification. However, flow considerations indicate that denitrification of digester supernatant would be useful only in preventing operating problems in other treatment units rather than effecting any great reduction of the overall plant nitrogen output in the effluent.

TABLE 8-5

CHARACTERISTICS OF DIGESTER SUPERNATANTS (mg/l)

Parameter	Overall Average	Range of Plant Averages	Range of Results
pH	7.0	5.9-7.7	5.7-8.0
BOD	500	9-1,700	5-6,350
Filtered BOD	51	4-183	3-280
COD	2,600	228-8,140	24-25,500
SS	3,400	46-11,500	9-41,800
Kjeldahl N	170	10-400	2.9-1,350
Total P	98	19-241	2.1-930
Soluble P	26	2.5-64	0.4-120

PROCESS CONTROL

In most cases, the process state of the digester can be established by the DO level, the oxidation-reduction potential (ORP), and the nitrate concentration. If all of these values are high (DO greater than 1mg/l, ORP greater than 400mv E_h, and nitrate nitrogen greater than 10mg/l, the process is normally performing satisfactorily. Nitrate nitrogen values as high as 100mg/l have been observed in second-stage digesters. The nitrate concentration, the DO in the digester, and the ORP were all observed to be low (0mg/l nitrate N, less than 0.5mg/l DO, and ORP values less than 250mv) in digesters that did not perform satisfactorily. Low DO levels are most common at high temperatures, while at low temperatures, there is usually no problem in maintaining a residual DO.

The oxygen utilization rates of digester sludges have ranged from 5.7mg/l/hr at 21°C to 45mg/l/hr at 25°C. Most rates are in the range of 10-35mg/l/hr.

Oxygen Requirements

The oxygen uptake rate of aerobically digesting sludge depends on the temperature, the type of sludge fed into the digester, and the sludge age of the digesting sludge. In order to compare the digesters on an absolute basis, all oxygen uptake rates have been determined and reported as specific uptake rates. The specific uptake rate is calculated by dividing the oxygen uptake rate (mg/l/hr) by the concentration of VSS expressed in grams (gm/l). The specific uptake rate is then the oxygen consumption in mg per hour per unit weight of VSS (mg O_2/gm VSS/hr.). When comparing specific uptake rates of several plants, it is important to note that the treatment process associated with the aerobic digester governs the sludge age of the solids being wasted to the digester. Primary sludge has undergone no aeration at all, while waste activated sludge solids may have been aerated for 3 days (conventional plant) or up to 25 days (extended aeration plant). This must be considered in order to determine the oxygen requirements because primary sludge will promote sludge synthesis, whereas waste activated sludge is already in a state of endogenous respiration.

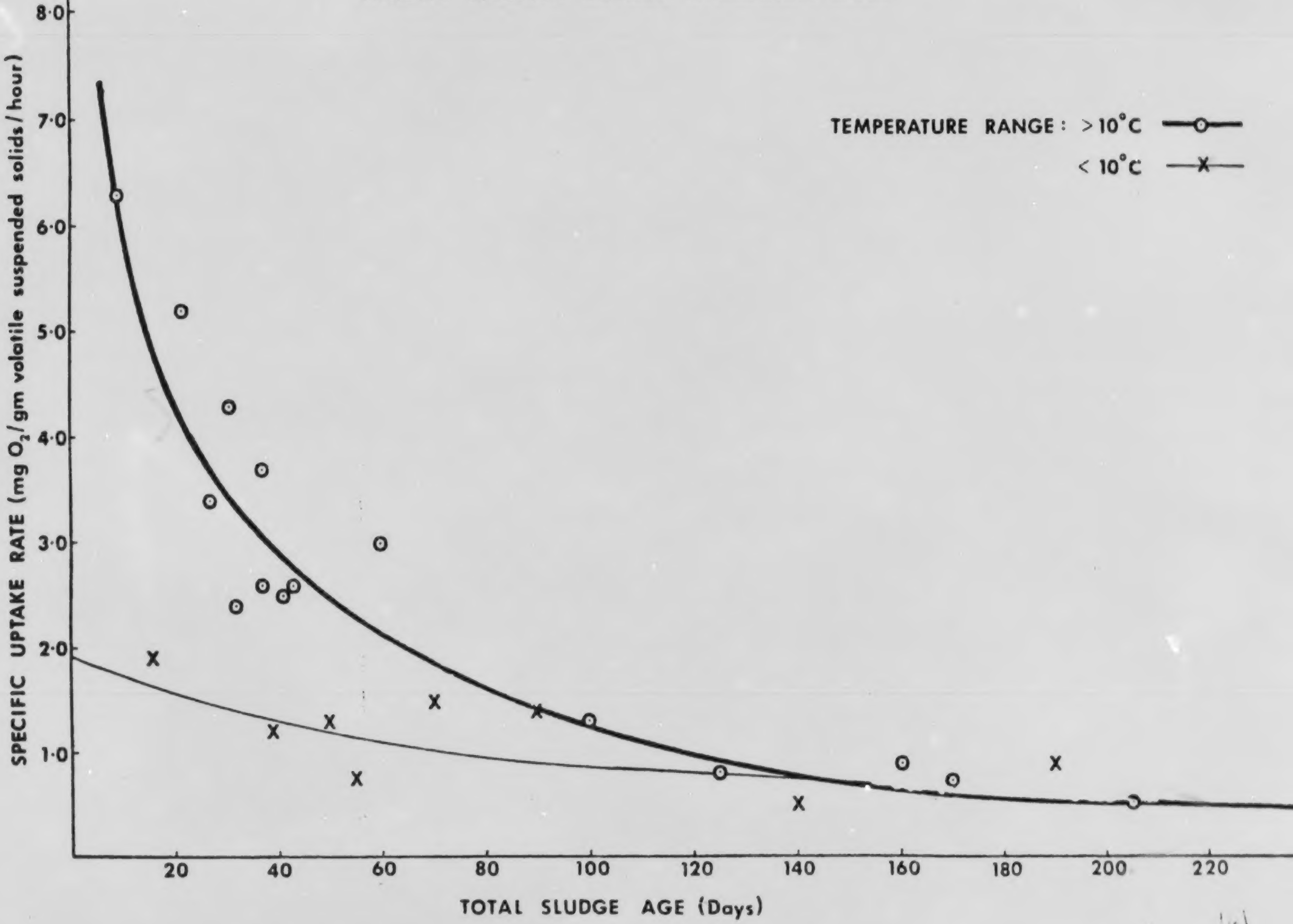
The specific uptake rate in the first- and single-stage aerobic digesters ranged from 0.5 to 6.3 mg O_2/g VSS/hr. Most of the data for first-stage and single-stage digesters was in the range of 2-4 mg O_2/g VSS/hr. The range for second-stage digesters was 0.5-2.4 mg O_2/g VSS/hr. Specific uptake rates of primary sludges in excess of 40 mg O_2/g VSS/hr were measured. Specific uptake rates of waste activated sludge from conventional activated sludge plants are normally in the range of 10 to 15 mg O_2/g VSS/hr. Waste sludges from contact stabilization plants have specific uptake rates of less than 10 mg O_2/g VSS/hr.

In Figure 1, the specific uptake rate has been plotted against the total sludge age (age in the digester plus the age of the solids when wasted to the digester) of the digesting solids. The data have been plotted for two temperature ranges, below and above 10°C. Most digesters in the Province of Ontario are below 10°C for five months of the year during the winter. At low sludge ages, the temperature inhibits the rate of biological activity. At high sludge ages, greater than 100 days, the biological activity is so low that the temperature has little additional effect.

From a unit process viewpoint, a sludge age of approximately 100 days represents the desired stability as far as the aerobic digestion process is concerned. However, at most installations, it is economically impractical to provide digester capacity to achieve a completely stable sludge. The stability of the sludge required at a particular installation depends on the method of ultimate disposal and the local restraints on disposal. Land disposal is the principal means of ultimate sludge disposal in the Province of Ontario. Because the depth of application is very shallow

FIGURE 8-1

AEROBIC DIGESTER OXYGEN UTILIZATION RATES



and the possibility of putrefaction is minimal, sludge ages as low as 45 days may be accepted for the design of aerobic digesters. Where local conditions demand a more stable sludge, a sludge age of 90 days is considered acceptable. Two-stage digesters would be necessary to make the solids concentration one that minimizes the haulage costs but does not exceed a realistic air supply rate.

Consider a two-stage aerobic digester operating at a sludge age of 45 days providing equal sludge ages in each stage with a total solids concentration of 3% in the first stage and 6% in the second stage. Assume that the volatile fraction of each sludge is approximately 50%. From Figure 1, at a sludge age of 22.5 days, the specific oxygen uptake rate is approximately 4 mg O_2/g VSS/hr. The maximum oxygen uptake rate in the first stage digester would be approximately 60 mg O_2/l/hr. At a sludge age of 45 days, the specific oxygen uptake rate is approximately 2.5 mg O_2/g VSS/hr. The maximum oxygen uptake rate in the second stage digester would be approximately 75 mg O_2/l/hr. Thus, oxygen requirements will be similar in both stages of digestion. Aeration equipment should be capable of satisfying an oxygen uptake rate of 60-70 mg O_2/l/hr.

Physical Operations

In order to waste sludge to the digester, some of the digester contents, preferably as supernatant, must first be removed. This may be accomplished by shutting off the aerator to obtain supernatant. The supernatant volume removed daily could be as much as 10% of the first digester volume. This is either removed before sludge wasting or displaced by the waste sludge fed to the digester. The supernatant is returned to the activated sludge plant for further treatment. The sludge in the digester is concentrated by repeated supernatant draw-off, increasing the oxygen requirements. In order to satisfy the oxygen requirements and to produce a stable concentrated sludge, a second-stage digester is required to complete the sludge stabilization when the oxygen requirements of the sludge in the first stage exceed the oxygen supply available (at approximately 3 percent TS). A solids concentration of 6 percent has been attained in some second-stage digesters. Further concentration of the sludge is difficult because of poor settleability.

Sludge is wasted from aerobic digesters either when the digester is full and poor sludge settleability does not permit supernatant draw-off and additional wasteage to the digester or when the available air supply cannot supply a residual DO. In neither case is there any assurance that the sludge has been stabilized.

In the past, sludge stability has been determined by the percent reduction of VSS. This has not proved to be a reliable means of assessing sludge stability because of periodic fluctuations in the volatile fraction of the sludge wasted to the digester. In some cases, the average volatile fraction of digesting sludge has increased. A complete mass balance would be necessary to determine accurately the sludge stability by the reduction of VS. Data from this study indicate that with high sludge ages, the volatile fraction of the sludge approaches a minimum value, indicating a maximum VS destruction of approximately 45 percent.

The specific uptake rate is a more reliable indication of digested sludge stability because it is a measure of biological activity. Because the purpose of the aerobic digestion process is to biologically oxidize organic compounds to stable organic and inorganic end products, and because the biological activity decreases as the unstable organic fraction of material in the sludge decreases, this measure of biological activity (specific uptake rate) is an absolute basis of sludge stability that is not peculiar to an individual plant. Figure 1 shows the effect of sludge age and temperature on the specific uptake rate. While this rate is temperature dependent, it is still possible to select a level of activity, depending on the temperature, that indicates that a sludge is sufficiently stabilized for purposes of ultimate disposal.

PROBLEM AREAS

Certain problems were found in all of the digesters studied. Some problems were of a general nature, while others were unique (related to the type of wastes received by a digester).

Mixing

All digesters under investigation were checked for adequacy of mixing, determined by the amount of solids deposition in the digesters. Because operation of the digesters requires the periodic removal of supernatant, mixing requirements for digesters must include the capability of resuspending settled solids that have accumulated during the settling period before supernatant removal.

Samples of deposited solids in all but one digester were characterized by low volatile fractions, suggesting grit as the source of the solids. The one exception experienced the most severe problem of solids deposition, which seemed to result from inadequate mixing.

It is believed that solids deposition in the digesters results from a number of factors including the method of operating the digester, tank configuration, location of air diffusers, solids concentration in the digester, and type of sludge fed to the digester.

Regardless of the source of deposited solids in the digesters, the result is the same: the loss of digester capacity. Aeration devices should be capable of maintaining a solids concentration of 6 percent in suspension and resuspending this concentration following a long settling period.

Temperature

The principal physical effects of temperature extremes have been foaming at high temperatures and icing at low temperatures. Some foam was observed on the surface of all digesters throughout the year, but to a lesser extent during the winter. Analysis of digester samples did not reveal any correlation between the amount of ether-soluble material and the quantity of foam. High temperature seems to have encouraged foaming.

At low temperatures ($0^{\circ}C$), ice formation in several digesters caused operational problems. In one installation, a piece of ice approximately 20 ft. in diameter formed in the digester. Liquid turbulence and wind occasionally carried the ice into the side of the tank, breaking off the air diffuser drop pipes, which are located around the tank circumference. In another case, the digester was covered with 6 to 8 inches of ice except for the openings above the air diffusers.

Metal Toxicity

Metal analyses were carried out on all digester contents as well as on the occasional supernatant sample. Because toxicity is primarily caused by ions, several digester samples were filtered to determine the concentration of metals in solution. The data were collected to establish whether industrial wastes were affecting the performance of certain plants. Most other plants had very few sources of industrial wastes and provided a basis for comparison. Filter samples from these plants were analyzed to determine metal concentration for copper, chromium, nickle, zinc, aluminum, lead, cadmium, manganese, and iron. The concentrations were all below 1 mg/l. High metal concentrations were observed in plants receiving industrial wastes and in digesters where sludge ages exceeded 120 days. While the concentration of metals in solution was low in all digesters, this does not necessarily suggest that the metals do not inhibit digestion. This effect could not be established because of oxygen dificiencies in the digesters receiving industrial wastes. The high metal concentrations in digested sludges from plants receiving industrial wastes could pose a long-term problem if the sludge were ultimately disposed of on agricultural land.

General Design Considerations

Factors that affect the temperature operating range of aerobic digesters include the hydraulic retention times, heat sources and heat sinks in terms of the air supply and the wastewater flow through the treatment plant, and the construction characteristics of the digester.

While relatively long retention times cannot be avoided if a stable sludge is expected, the temperature effects can be minimized. The air supply is one heat source that can be utilized by insulating the header or minimizing the length of air header to the tank. This method of conserving heat could be economically impractical. Perhaps the simplest method of regulating the temperature of the digester contents is the use of common wall construction. A digester with steel walls in common with the activated sludge tanks would maintain a temperature similar to that of the raw wastewater. Minimum temperatures of approximately 5°C would be encountered compared to the present situation of 0°C temperatures and associated icing problems.

The location of the digester can also be an important factor if the digester is an isolated tank. The worst possible situation for heat loss in winter is a steel tank completely above grade. Earth embankments around the tank placing the tank below grade, or coverings for the tank both represent an improvement in design.

The maximum temperature range observed in digesters in this study was $29C^{\circ}$ (0° to $29^{\circ}C$). In plants that have instituted some of the above factors for minimizing the temperature variation, the range has been as little as $11.5C^{\circ}$ (13.5° to 25°). The physical design becomes especially important if mechanical aerators are considered because one potential heat source available with diffused air systems is lost. Therefore, it is felt that their use should be avoided unless a heat source is available. The use of fine bubble diffused air aeration devices should also be avoided because the frequently repeated periods of settling before supernatant removal afford too great an opportunity for plugging. Coarse bubble diffusers of a design that is not prone to plugging should be used. Because no assurance can be given that plugging will not occur, the diffuser mountings should permit removal of the units without draining the digester. As well as providing sufficient oxygen for biological activity, the aeration device must also be able to keep a high solids concentration (approximately 6 percent) in suspension and resuspend the solids after the settling period.

SUMMARY

1. The aerobic digestion process can produce a stable sludge. The design should provide a sufficient solids retention time rather than a specific hydraulic retention time. Oxygen requirements will depend on the solids retention time and the maximum solids concentration in the digester.
2. While a reduction of VS does occur during aerobic digestion, the percent reduction of VS cannot be used to reliably indicate the stability of sludges from digesters under continual loading conditions. The specific oxygen uptake rate is one of the most reliable indicators of the conditions and stability of aerobically digested sludge. This rate is temperature dependent.
3. Aerobic digestion produces a low organic-strength supernatant that represents an insignificant load when returned to the activated sludge process. Nutrient return from aerobic digesters normally represents less than 5 percent of the total plant nutrient flow.
4. To insure sludge stability and to effect concentration of the sludge, a two-stage digestion system is required. Settling characteristics of digesting sludge deteriorate with increasing solids concentrations and low residual DO levels.

5. Air flow rates of 20 cfm/1,000 cu ft capacity have resulted in solids deposition and oxygen deficiencies in some digesters.

6. Operational problems occur with extremes of temperature. Foaming has occurred at high temperatures and icing at low temperatures. Temperature extremes in the digester can be minimized by the physical plant design.

SUBJECT:

PROCESS CONTROL

TOPIC: 9

SAMPLING AND INTERPRETATION

OBJECTIVES:

The trainee will be able to:

1. Recall the purpose of sampling.
2. Define:
   a. grab sample
   b. composite sample.
3. Recall the location and types of samples to be taken in a plant.
4. List the routine analyses to be done on each sample in:
   a. an aerobic system
   b. an anaerobic system.
5. Apply the results of analyses in plant calculations.

SAMPLING AND INTERPRETATION

SAMPLING

PURPOSE

Sewage is treated to produce an effluent which will not impair the quality of the environment. If spending money is necessary to reduce pollution, then a knowledge of plant performance is necessary to justify the cost and to assess the treatment. *The purpose of routine sampling is to obtain data concerning the physical, chemical and biological characteristics of the waste stream regardless of the size or type of plant. This information can be used for control of the treatment processes, to show that regulations or standards have been observed, for estimating the effect of plant effluent on the receiving waters and for design of plant extensions.*

TYPES OF SAMPLES

Grab Sample

A *grab sample* can be defined as a single sample of wastewater taken without considering the time or the rate of flow. It is not very useful for calculating a waste loading since a single aliquot is not usually representative of average conditions. *Grab samples are only of value in determining the composition of either maximum or minimum flows.*

Composite Sample

A *composite sample* is defined as one which is built up, or composited from a series of grab samples taken at intervals during a fixed sampling period. It represents the average characteristics of the waste flow over the survey period and may be used to calculate waste loadings using the flow volume over the same period.

Composite samples are of the two types:

1. Those in which the grab samples are kept separate and analyzed separately to enable variations to be determined.

2. Those in which the grab samples are combined to form a bulk sample, all or part of which is subjected to analysis.

In the first type, a constant volume is taken at each interval regardless of the flow rate at that time. However, if a waste loading is to be calculated and it is known that the flow rate is not constant, the flow rate must be measured when each sample is taken.

In the second type of composite, where the aliquots are combined, a constant volume is taken at each interval only when the flow rate is constant. Where the flow rate varies, the amount of the aliquot taken at each interval must change in proportion to the flow rate *at the time when the sample is withdrawn from the waste stream.* For example, if at one sampling time the measured flow rate is 150,000 gpd and an aliquot of 500 ml is taken, at the next sampling only 250 ml should be taken if the measured flow rate is 75,000 gpd.

A constant time interval is usually chosen between aliquots of a composite sample, since most variations in waste characteristics occur on a time cycle. The time allowed between aliquots is determined by the variability of waste characteristics. If the characteristics vary rapidly, the aliquots must be taken frequently, say every half hour, while if the waste is of fairly uniform character, the intervals may be longer, say every hour. The most accurate average will, of course, be given by a continuously drawn sample, but unless automatic equipment is used, this will not be practical. Therefore, longer intervals, such as 10, 15, or 30 minutes are often used. However, aliquots should never be taken less than once per hour. A similar principle applies when characteristics vary with volume.

To give an accurate picture of the overall quality of raw sewage entering, of plant effluent leaving, and of the processes going on within the plant, a series of three 8-hour composite samples over a 24-hour period is the ideal, and is *strongly recommended. Daylight hour 8-hour composites are the next best choice, if sampling cannot be done regularly at night. In this case the occasional night composite should be attempted, even if this requires shortening a day shift to accommodate the extra hours worked.*

TYPES OF SAMPLING DEVICES

There are two types of sampling devices, *automatic* and *manual*. Examples of each with their advantages and limitations are as follows:

1. Automatic
    - a) Vacuum Sampler

      This apparatus consists of an evacuated sample container, an electrically (or mechanically) operated closing device and a length of tubing. The open end of the tube is placed in the waste stream and the timing mechanism is set to operate at the required intervals. When the closing device is opened, wastewater is drawn into the container.

      Advantages of this apparatus include simplicity, reasonable cost and ability to function for long periods on a small storage battery. Its chief limitation is that it can only be used on a minimum lift.
    - b) Pump Sampler

      This apparatus consists of a sample container, a pump, and interconnecting tubing. Many types of pumps may be used, among the most useful being chemical feed pumps, due to their ability to meter accurately small volumes of liquid. A timing mechanism may be incorporated.

      Both vacuum and pump samplers may be equipped to sample in proportion to the flow rate.

In addition to the two types described above, there are many others based on similar principles and on various types of wheels, discs and rotating scoops.

2. Manual

   Equipment used in manual sampling is simple and consists of bottles, lines, poles (able to be joined together), bucket or bottle holders, and weights.

COLLECTION OF SAMPLES

General

In keeping with the prime objective of a sampling programme (to obtain accurately representative samples), certain precautions must be taken to avoid errors. Whatever type of container is used, it must, of course, be "clean"; rinse with sample to be taken, or clean water.

NOTE: When samples are taken through the plant, a good technique is to start with final effluent, primary effluent, raw sewage, activated sludge, and sludge return, raw sludge in digester samples. This sequence will prevent cross-contamination of samples. Where smaller samples are to be taken from a larger sample, care should be taken that the sample is representative (shake or stir sample well to ensure a thoroughly mixed smaller sample).

REMEMBER: *THE ANALYSIS IS ONLY AS GOOD AS THE SAMPLE TAKEN!*

Taking good, representative samples of the wastewater entering and leaving the treatment plant is extremely important. The type of sample, where it is taken and how it is taken require conscientious care and attention since they will greatly influence the reliability of the data obtained.

The following points must be considered when taking a sample as well as where the sample is taken:

1. A grab sample is most useful when some questionable material is seen in the raw waste.
2. Because of the variation in loadings throughout the day, composite samples are essential. Each grab sample making up the composite sample should be kept refrigerated in a clean container.
3. In some cases, an automatic sampler will be used to obtain a 24-hour sample; this equipment should take the sample proportional to the flow.

Sampling Locations and Tests Required

Figure 9-1 is a block diagram of an aerobic system. Table 9-1 lists the tests required at the various locations indicated in Figure 9-1.

Figure 9-2 is a block diagram of an anaerobic system. Table 9-2 lists the tests required at the various locations indicated in Figure 9-2.

When submitting samples for laboratory testing, these tables should be used as a guide to ensure the required tests are conducted.

For laboratory test procedures refer to:-

1. Topic 10 Suspended and Volatile Suspended Solids
2. Topic 11 Total Solids and Total Volatile Solids
3. Topic 12 Dissolved Oxygen
4. Topic 13 Oxygen Uptake Role
5. Topic 14 BOD
6. Topic 15 pH
7. Topic 16 Volatile Acids and Alkalinity

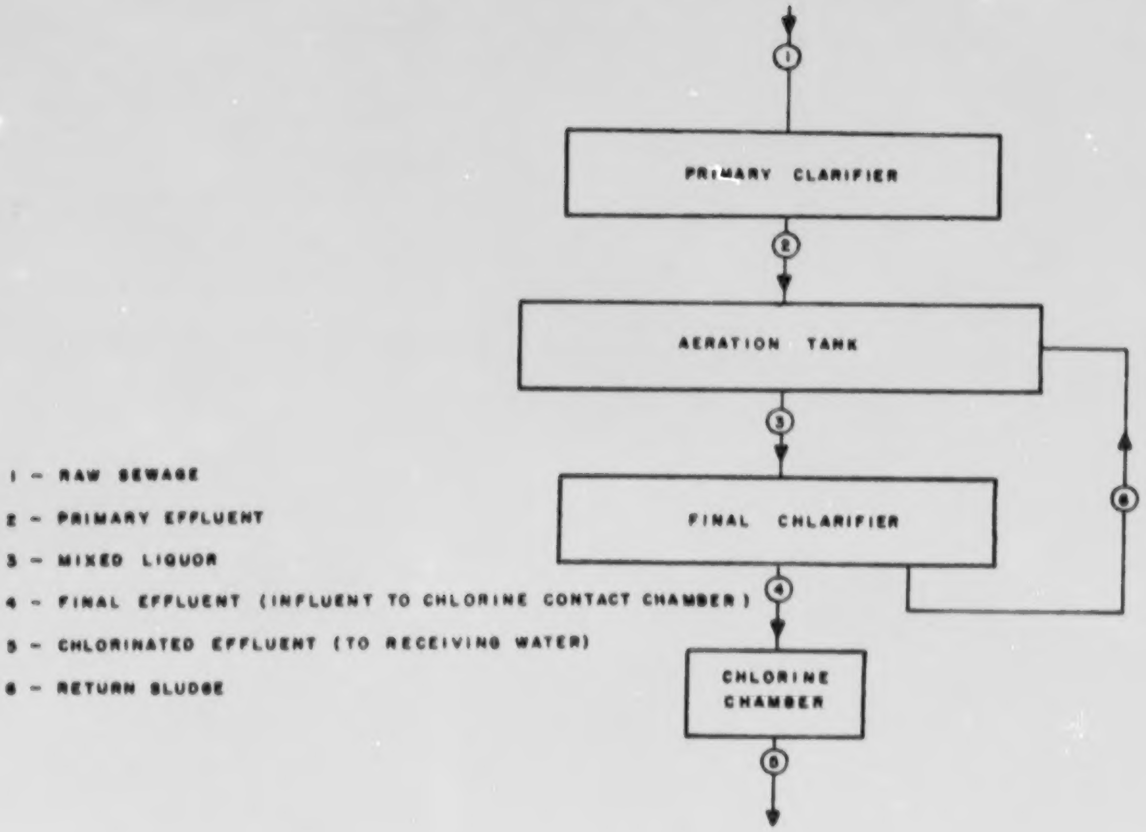

①
PRIMARY CLARIFIER
②
AERATION TANK
③
FINAL CHLARIFIER
⑥
④
CHLORINE CHAMBER
⑤
1 - RAW SEWAGE
2 - PRIMARY EFFLUENT
3 - MIXED LIQUOR
4 - FINAL EFFLUENT (INFLUENT TO CHLORINE CONTACT CHAMBER)
5 - CHLORINATED EFFLUENT (TO RECEIVING WATER)
6 - RETURN SLUDGE

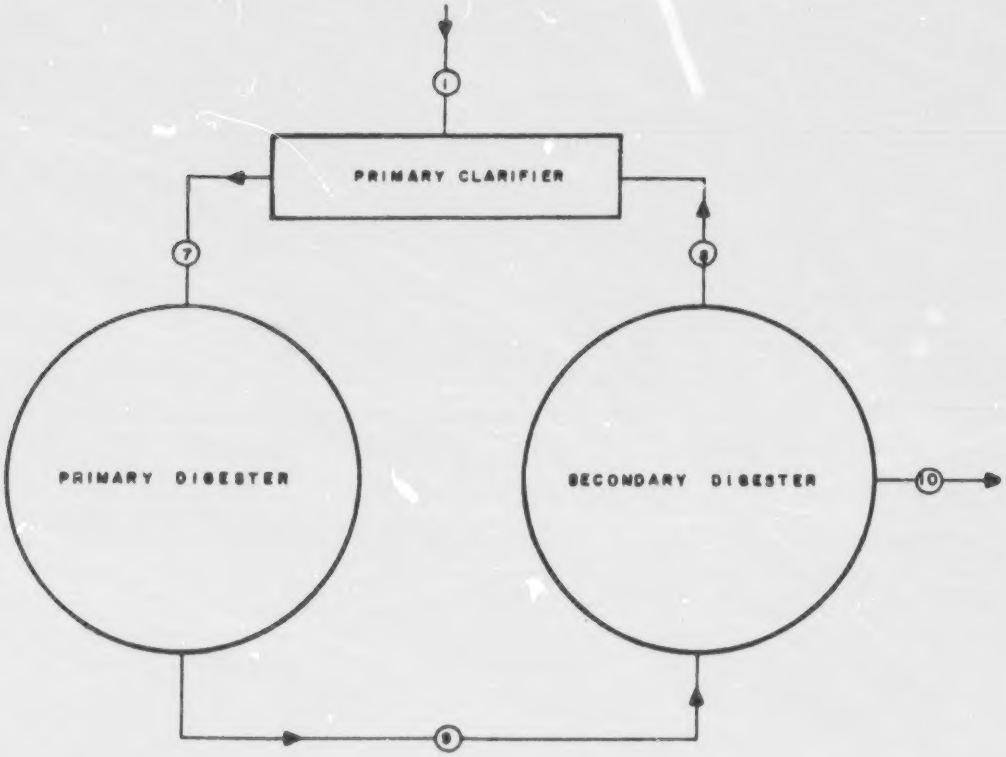
FIGURE No 9-1

SAMPLING LOCATIONS WITHIN AEROBIC SECTION

TABLE 9-1

ROUTINE ANALYSES REQUIRED IN AEROBIC SYSTEMS

			SOLIDS					
SAMPLE	No.	BOD	TOTAL	SUSPENDED	DISSOLVED	VOLATILE SUSP.	Cl_2 RESID.	pH
RAW SEWAGE	1	X	X	X	X	X		X
PRIMARY EFFLUENT	2	X	X	X	X			X
MIXED LIQUOR	3			X		X		X
FINAL EFFLUENT	4	X	X	X	X			X
CHLORINATED EFFLT.	5						X	
RETURN SLUDGE	6			X		X		X


1
PRIMARY CLARIFIER
7
8
PRIMARY DIGESTER
SECONDARY DIGESTER
10
9

1 - RAW SEWAGE
7 - RAW SLUDGE
8 - SUPERNATANT LIQUOR
9 - SLUDGE TRANSFER
10 - DIGESTED SLUDGE

FIGURE No.9-2
SAMPLING POINTS WITHIN ANAEROBIC SECTION

TABLE 9-2

ROUTINE ANALYSES REQUIRED IN ANAEROBIC SYSTEMS

SAMPLE	No.	SOLIDS		VOLATILE ACIDS	ALKALINITY	pH
		TOTAL	VOLATILE			
RAW SLUDGE	7	X	X			X
SUPERNATANT LIQUOR	8	X	X	X	X	X
SLUDGE TRANSFER	9	X	X			X
DIGESTED SLUDGE	10	X	X			X

Safety in Sampling

No sample is worth obtaining at the risk of life and limb. Safety precautions should be observed at all times, including the following:

1. Never sample alone at night where lighting is poor.
2. Never enter a tank or other vessel or a sewer unless it cannot be avoided, and then *only when it is known that the atmosphere is free from noxious gases and there is no possibility of any material entering while sampling is in progress.* Never do it alone and always use a lifeline.
3. Always remember that most organic liquids are highly inflammable and form explosive mixtures with air. *Smoke only in safe places and when sampling is completed.*
4. All chemical substances must be considered harmful (until proven otherwise) if ingested into the stomach or lungs, or by contact with the skin and eyes. It is vital to know what materials may be encountered during a survey and to use all necessary protective devices.

INTERPRETATION OF TEST RESULTS

Biological Oxygen Demand (BOD)

Topic 14 describes the laboratory procedure for determining BOD_5. The results are an indication of the organic component of the sewage which along with the flow can be used to calculate the organic load to be imposed on the aeration section. It can also be used to calculate the efficiency of removal of organic material in the primary clarifier and the overall BOD removal in the plant. Knowing the amount of oxygen required to oxidize a given amount of BOD, it is then possible to determine whether or not sufficient air is being delivered to cope with the organic load. In an efficiently operating primary clarifier, BOD_5 removal should be 30-40 per cent.

Solids Determination

Total solids are required as a prerequisite to determining the volatile content of the sludge or as one step in producing a suspended solids figure by difference. In raw sludges, the total volatile solids are used to calculate the amount of food being fed to a digester or the amount of material leaving a digester. Suspended solids are used to determine the solids removal efficiency of the clarifier and to calculate the weight of solids removed from the raw sewage.

The weight of volatile solids not only tells the operator the weight of organic food being fed to the anaerobic digester. Knowing that each pound of volatile matter destroyed is expected to produce a quantity of digester gas, the estimated amount of gas that should be produced can be calculated. The heating value of the gas and the length of time that the burner can be operated can be determined.

Calculations

Remember: *1 ppm = 1 mg/l = 1 lb/100,000 gals.*
1 mg/l = 10 lbs/1,000,000 gals.

1. Digester Retention Time

This is a function of digester volume and raw sludge feed rate.

e.g. digester volume = 100,000 gallons
raw sludge feed rate = 5,000 gpd

$$\text{Retention Time} = \frac{100,000}{5,000} = 20 \text{ days}$$

In two-stage systems, only the primary volume is used in calculating retention time.

2. Clarifier Efficiency

This is a function of the raw sewage BOD, primary effluent BOD and flow.

Example:

BOD in Raw Sewage	325 mg/l
Primary Effluent BOD	165 mg/l
Flow	1,250,000 IGPD

Determine:

a. BOD_5 (lb/day) applied to the aeration tank (or going to chlorine contact chamber).

b. % BOD_5 reduction across the primary clarifier (clarifier efficiency).

Solution a.

lbs/day BOD_5 to aeration tank

= primary effluent BOD_5(mg/l) x flow IGPD x 10 lb/gal

$$= 165 \times \frac{1,250,000}{1,000,000} \times 10 = 2062.5 \text{ lbs } BOD_5\text{/day}$$

or say 2060 lbs/day BOD_5

Solution b.

Primary Clarifier Efficiency

$$= \frac{\text{Raw Sewage BOD-Primary Effluent BOD}}{\text{Raw Sewage BOD}} \times 100$$

$$= \frac{325-125}{525} \times 100 = 49.2\%$$

3. Solids Reduction Performance

Solids reduction performance is based on the results of analyses conducted on the raw, primary and digested sludge samples. Knowing the daily flow and having determined by analysis the suspended and volatile suspended solids in the raw sewage and primary effluent, the operator can determine:

a. per cent volatile solids in the raw sewage and primary effluent;
b. lbs solids deposited in the primary clarifier(s);
c. lbs of volatile solids applied to the digester;
d. per cent solids removal across the primary clarifier(s).

Example:

Given:-

Raw Sewage Suspended Solids	325 mg/l
Raw Sewage Volatile Suspended Solids	227.5 mg/l
Primary Effluent Suspended Solids	215 mg/l
Primary Effluent Volatile Susp.Solids	161 mg/l
Daily Flow	2.35 MIGPD

Determine a. to d. inclusive above.

a. % Raw Sewage Volatile matter

$$= \frac{\text{Raw Sewage Volatile Suspended Solids}}{\text{Raw Sewage Suspended Solids}} \times 100$$

$$= \frac{227.5}{325} \times 100 = 70\%$$

For primary effluent, using data given above

% primary effluent volatile susp. solids

$$= \frac{161}{215} \times 100 = 74.9\%$$

b. Weight of solids in primary clarifier (lbs/day)

= (Raw Sewage Susp. Solids - Primary Eff.Susp. Solids) x flow

$$= (325 - 215)\text{mg/l} \times 10 \times \frac{2,350,000}{1,000,000}$$

= 2585 lbs/day

c. lbs/day volatile solids to the digester

= lbs/day solids in primary clarifier x % Vol. Susp.Solids

= 2585 x 70%

$$= 2585 \times \frac{70}{100}$$

= 1809.5 or 1810 lbs/day volatile suspended solids.

d. % solids removal across the primary clarifier(s)

$$= \frac{\text{Raw Sewage Susp. Solids-Primary Effl.Susp.Solids}}{\text{Raw Sewage Suspended Solids}} \times 100$$

$$= \frac{325 - 215}{325} \times 100 = 33.8\%$$

4. Raw Sludge Feed To Digester

Knowing the raw sludge suspended solids content and the characteristics of the raw sludge feed pump, the operator can calculate the lbs/day raw sludge fed to the digester.

Example:

Raw sludge Suspended Solids	45,000 mg/l
Raw sludge pump feed rate	50 IGPM
Pumping Cycle	12 minutes
Number of Cycles	6/day

Assume specific gravity of sludge is 1.0.

a. Number of gallons of sludge pumped:

= pump capacity (IGPM) x cycle x number of cycles/day
= 50 x 12 x 6
= 3600 IGPD

b. Solids Loading

= mg/l raw sludge x wt/gal x gals pumped

$$= 45000 \times \frac{10}{1{,}000{,}000} \times 3600 = 1620 \text{ lbs/day}$$

c. % Volatile Solids To Digester

Given the raw sludge volatile solids are 73.6% and the solids loading (b. above) is 1620 lbs/day, lbs/day volatile solids:

$$= \text{Raw Sludge Solids loading} \times \%\ \text{Volatile Solids}$$

$$= \frac{1620 \times 73.6}{100} = 1192\ \text{lb/day volatile solids}$$

The weight of the raw sludge volatile solids not only tells the operator the weight of organic food applied to the anaerobic digester, it is used to determine the amount of digestion which takes place in the digester and the amount of gas that should be produced.

5. Digester Loading

The loading on a digester is usually expressed as lbs Total Volatile Solids (TVS) per cubic foot (ft^3) per day (lbs TVS/ft^3/day). For example, if the raw sludge feed rate is 5000 IGPD and the total solids (TS) and TVS are 5.1% and 62.3% respectively, then the lbs TVS applied are:

$$\text{Feed Rate (lbs/day)} \times \%TS \times \%TVS$$

$$= 5000 \times 10 \times \frac{5.1}{100} \times \frac{62.3}{100} = 1589\ \text{lbs TVS/day}$$

If the primary digester volume is, say, 15000 ft^3, the loading is -

$$\frac{1589\ \text{lbs TVS/day}}{15000\ ft^3} = 0.11\ \text{lbs TVS}/ft^3/\text{day}$$

6. Volatile Solids Reduction

a. To determine the reduction in Volatile Solids by digestion the following formula is used:

$$P = 1 - \frac{(100 - R)D}{(100 - D)R} \times 100$$

Where P = per cent reduction of volatile matter,
R = per cent volatile solids in the raw sludge, and
D = per cent volatile solids in the digested sludge.

Example

Given:

R = 73.5 per cent
D = 49.8 per cent

then

$$P = 1 - \frac{(100-73.5)49.8}{(100-49.8)73.6} \times 100$$

$$= 1 - \frac{26.5 \times 49.8}{50.2 \times 73.5} \times 100$$

$$= 1 - \frac{1{,}319.7}{3{,}689.7} \times 100$$

$$= 1 - .3577 \times 100$$

$$= .642 \times 100$$

$$= 64.2 \text{ per cent}$$

b. Another method of calculation based on the availability of different data is shown below.

Example:

For a two-stage system, the following analytical results were available:

(1) Raw Sludge

Solids	
Total	Volatile
5.1%	62.3% of Total Solids

(2) Primary Sludge

Solids	
Total	Volatile
3.4%	51.4% of Total Solids

(3) Digested Sludge

Solids	
Total	Volatile
2.8%	50.0% of Total Solids

The general equation is:

% Volatile Solids Reduction =

$$100 \quad 1 - \frac{\% \text{ Ash in Raw} \times \% \text{ Volatile in Digester}}{\% \text{ Volatile in Raw} \times \% \text{ Ash in Digester}}$$

then the volatile solids reduction performance in the primary digester would be:

$$100 \quad 1 - \frac{37.7 \times 51.4}{62.3 \times 48.6} = 36\%$$

This is based on the results shown under (1) and (2) above. The % ash in the calculation is equal to: 100 - % volatile solids.

The performance of the secondary digester would be based upon the results under (2) and (3) with (2) being regarded as the raw sludge in this case.

The overall digester volatile solids reduction performance would be based on the results under (1) and (3).

In the example, this would be:

$$100 \quad 1 - \frac{37.7 \times 50.0}{62.3 \times 50.0} = 39\%$$

7. Digester Gas Produced Per lb Volatile Solids Reduce

Knowing the amount of digestion or % reduction volatile solids, the operator should be able to calculate the approximate quantity of gas that would be produced.

a. In 5.c above, it was determined that 1192 lbs volatile solids were added to the digester. In 7.a it was determined that there was 64.2% reduction. It is also known that 1 lb volatile solids destroyed produces 12-18 cu.ft. of digester gas. If this gas is 65% methane, the BTUs produced can be calculated. Using these data amount of gas produced:

$$= \text{lbs Volatile Solids pumped to digester}$$

$$\times \frac{\%\ \text{Reduction}}{100}$$

$$= 1192 \times \frac{64.2}{100}$$

= 765 lb. of volatile solids destroyed.

Using the average of 15 cu.ft/lb of volatile solids destroyed, the digester gas produced would be:

765 x 15 = 11475 cu.ft of gas/day.

b. If the operator wishes to compare his operation to what might be considered a standard, another calculation can be carried out. In paragraph 7.b above, reduction performance of the primary digester was seen to be 36%. If the raw sludge feed rate to the primary digester was say, 15,000 gpd, then the pounds of volatile solids applied would be:

$$15{,}000 \times 10 \times \frac{5.1}{100} \times \frac{62.3}{100} = 4766 \text{ lbs/day}$$

where $\frac{5.1}{100}$ amd $\frac{62.3}{100}$ are the percentages of total and volatile solids respectively.

The factor, 10, converts gallons (Imperial) to pounds. If 36% reduction was achieved, this equals $4766 \times \frac{36}{100} = 1716$ lbs/day volatile solids reduced.

If the average gas production during this period was, say, 25,500 cubic feet per day, then the specific gas production, or cubic feet of gas per pound solids reduced is:

$$\frac{25{,}500}{1716} = 14.9 \text{ cu.ft gas/lb solids reduced}$$

This performance parameter generally varies between 10 and 20 cu. ft/lb solids reduced for various plants, depending on the characteristics of the raw sludge, and the efficiency of operation of the digester system.

8. BTUs Produced

a. If the methane content of the gas is, say, 67%, heat value factors can be applied and the actual heating value of the gas determined. The heat value factors are:-

(1) High Heat Value (HHV)
Multiply the % methane by 10.13

(2) Low Heat Value (LHV)
Multiply the % methane by 9.13

Given % methane = 67%

Then HHV = 67 x 10.13 = 678.7

or 679 BTU/cu.ft.

193

The LHV would be 67 x 9.13 = 611.7or 612 BTU/cu.ft.

In paragraph 8.a above, the amount of gas was determined to be 11475 cu. ft. Thus the highest heat output would be 11475 x 679 = 7,791,525 BTUs and the least heat expected would be 11475 x 612 = 7,022,700 BTUs.

b. An estimate of heat available can be obtained by assuming that a well burning gas will have a net heat content or value of about 600 BTU/cu.ft. Therefore, if a digester system produces say, 25,500 cu. ft. of gas daily, the BTUs available from the gas would be:

$$25{,}500 \times 600 = 15{,}300{,}000 \text{ BTU/day}$$

Assuming 85% boiler and heat exchanger efficiency, then

$$15{,}300{,}000 \times \frac{85}{100} = 13{,}005{,}000 \text{ BTU/day}$$

would be available for transfer to the digester.

If the total heat required were, say, 10,000,000 BTU/day, the excess gas would be wasted at the waste flare stack. If the heating requirements exceeded the heat available from the gas, an additional source of heat would be required, e.g. natural gas or fuel oil.

9 . Sludge Heating Requirements

If the raw sludge feed rate to the digester is, say, 15,000 gpd, and the raw sludge temperature is 50°F, the quantity of heat required to raise the temperature of the sludge to the digester operating temperature of 95°F is:

$$15{,}000 \times 10 \times 45 \times 1 = 6{,}750{,}000 \text{ BTU/day}$$

where the factors, 10,45, and 1 respectively are conversion of gallons to pounds, temperature differential, and specific heat. In addition, such digester has a heat loss which must be replaced by the plant heating equipment to maintain constant temperature. The magnitude of the heat loss varies depending on the size of the digester, extent of insulation, ambient temperature, etc., and the calculation is too lengthy for inclusion here. In general, a digester of 100,000 gallon volume will have a summer heat loss of about 1,000,000 BTU/day. Larger digesters may exhibit heat losses of 1.5 - 2.5 million BTU/day in winter. The sum of digester heat loss and heat required to raise the raw sludge to operating temperature is the total heat demand which must be supplied by the boiler, through the heat exchanger.

In some older plants, where difficulties are encountered in maintaining digester temperature, it is possible that current sludge feed rates are sufficiently increased over design flow rates to inundate the capacity of the heat exchanger. It is useful to the operator, therefore, to apply the calculation shown earlier to his own plant conditions and compare the sludge heat requirements with the heat exchanger specified output. Digester heat losses should be "questimated" using the rough examples included earlier as a guide.

SUBJECT:

PROCESS CONTROL

TOPIC: 10

SUSPENDED AND VOLATILE SUSPENDED SOLIDS

OBJECTIVES:

The trainee will be able to:

1. Carry out the test to determine suspended and volatile suspended solids.
2. Calculate, based on test results,
   - a) suspended solids
   - b) volatile suspended solids
3. Recall the normal sample aliquot required when testing
   - a) raw sewage
   - b) primary effluent
   - c) mixed liquor
   - d) return sludge
   - e) final effluent
   - f) aerobic and anaerobic digester supernatants
4. Define the following terms:
   - a) suspended solids
   - b) volatile suspended solids
   - c) aliquot

SUSPENDED AND VOLATILE SUSPENDED SOLIDS

GENERAL

The method proposed is based on the 13th edition of *Standard Methods*. A known sample volume is filtered through a glass fiber filter disk which has been weighed. The disk is then dried and weighed again: an increase in weight is due to the suspended solids in the sample. The disk is ignited at 550°C and weighed once more. The decrease in weight is recorded as volatile suspended solids.

There are several other methods by which suspended and volatile suspended solids may be determined including the Gooch Crucible procedure using either glass fiber disks or an asbestos mat, filter paper methods with low ash papers or Millipore paper, the double-dish method, centrifuge readings, and instrument methods, e.g. optical, radioactive and ultrasonic. However, the method proposed here is fast, easy to perform, and sufficiently accurate.

APPARATUS

1. Glass fiber filter disks, 9 cm diameter
2. Buchner funnel, size 2A for 9 cm filter paper
3. Filter flask or suction apparatus, attachable to vacuum source
4. Brass ring 3½ in. diameter, 1-3/4 in. high
5. Wide mouth pipets, 25 ml, 50 ml and 100 ml
6. Graduated cylinder, 500 or 1,000 ml
7. Convection type drying oven for use at 103°C
8. Muffle furnace for use at 550°C
9. Porcelain dishes to fit inside muffle furnace
10. Desiccator with self-indicating desiccant

11. Analytical balance accurate to 0.1 milligrams
12. Aspirator bulb
13. Forceps, flat nose, bent tip
14. Whatman No. 3 filter paper, 9 cm
15. Petri dishes, 100 mm diameter, 15 mm high
16. Wash bottle, polyethylene squeeze type
17. Long tongs
18. Pipet tray or stand

NOTE: If suspended and volatile suspended solids are only determined periodically (once or twice per week), the convection type drying oven should be preheated overnight, or at least one-half day prior to the solids determination. If suspended and volatile suspended solids are determined continuously, the convection type drying oven should be operated continuously at 103°C. The muffle furnace should be preheated to 550°C one or two hours before use.

FILTER DISK PREPARATION

1. Place glass fiber disk in desiccator overnight.
2. The following day, use forceps to pick up the filter disk; place on the analytical balance and weigh. (Figure 10-1)
3. Record the weight as "DRIED WEIGHT".

ANALYSIS OF SAMPLE(S)

1. Place a Whatman No. 3 filter paper in the Buchner funnel. Place the prepared glass filter disk with its wrinkled surface facing *upward* on the filter paper. (Figure 10-2)
2. Connect the above-assembled filtration apparatus to a vacuum source. Turn on the vacuum source.

3. Using distilled water, wet the filter disks to ensure that they are properly seated (Figure 10-3)

4. Pick up brass ring. Gently lower ring into Buchner funnel and place it concentric with filter disks.

5. Using a clean wide-mouth pipet with an aspirator bulb on the upper end or a graduated cylinder, measure out the selected volume of well-mixed sample. Let pipet drain by itself until liquid stops dropping by itself onto filter paper inside brass ring. The vacuum source will now "pull" the sample through the filter disk. Wash disk and brass ring with distilled water and allow to drain; disconnect the vacuum source. (Figures 10-4, 10-5 and 10-6)

6. Remove the brass ring without touching the residue on the filter disk. Using the forceps, grasp the outer edge of the disk (left clear and without any residue by use of the brass ring). Transfer the disk to its previously labelled Petri dish. Using tongs, pick up the dish and place in the convection type drying oven for one hour, with the temperature at 103°C. Remove and cool in desiccator. (Figures 10-7, 10-8 and 10-9)

7. Using forceps, pick up filter disk, place on analytical balance and weigh. (Figure 10-10)

8. Record the weight as "DRIED WEIGHT + SOLIDS".

9. If volatile suspended solids are to be determined, do the following:

   a) Use forceps to pick up filter disk whose "dried weight" and "dried weight + solids" have been determined, and place on procelain dish. (Figure 10-11)

   b) Use long tongs to pick up dish and transfer to muffle furnace which has been preheated to 550°C. (Figure 10-12)

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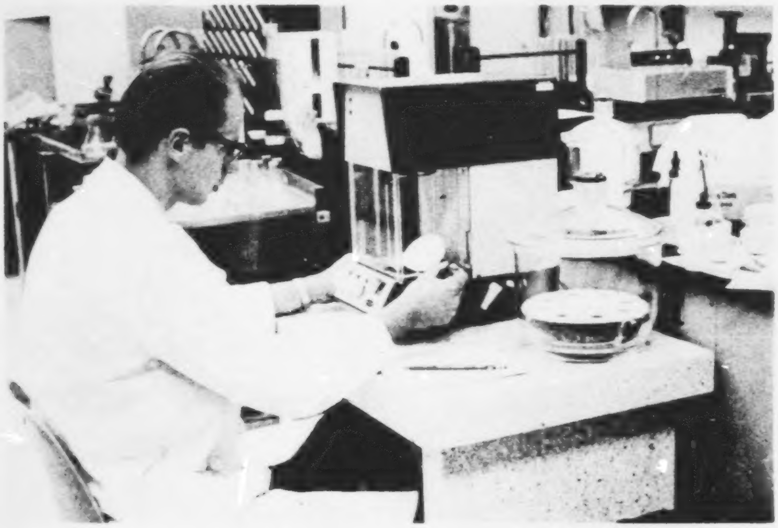

Figure 10-1

Pre-weigh glass filter disk.

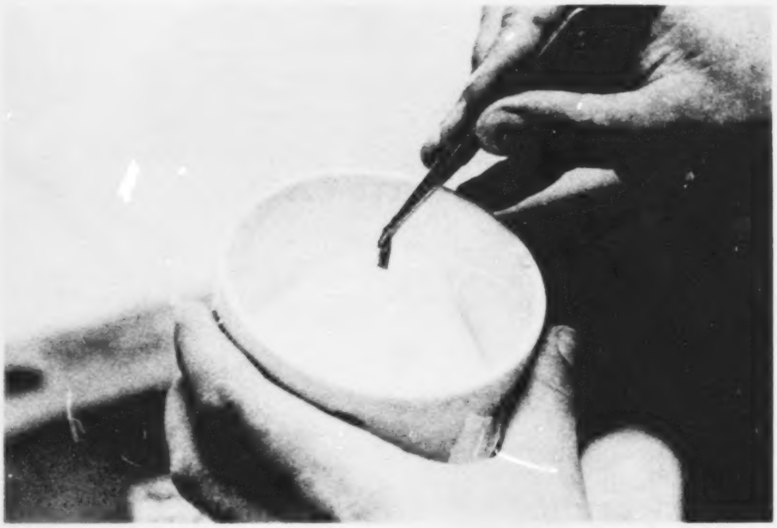

Figure 10-2

Place disk in funnel.

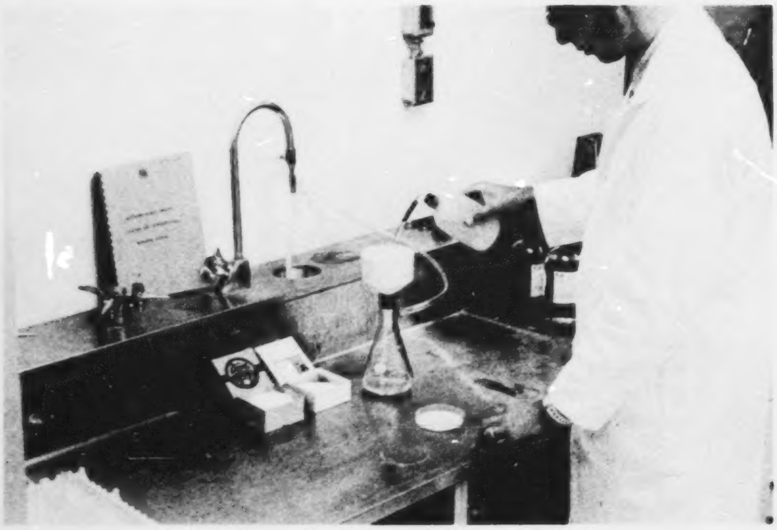

Figure 10-3

Wet filter disk using distilled water.

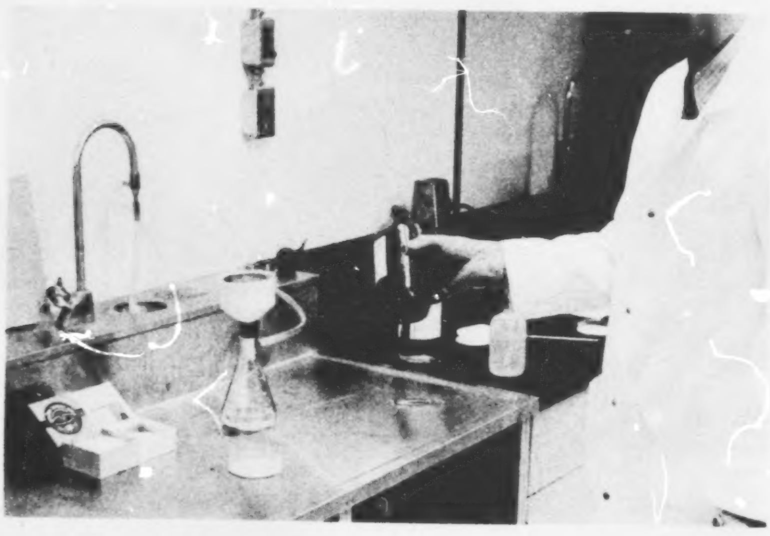

Figure 10-4
Mix sample.

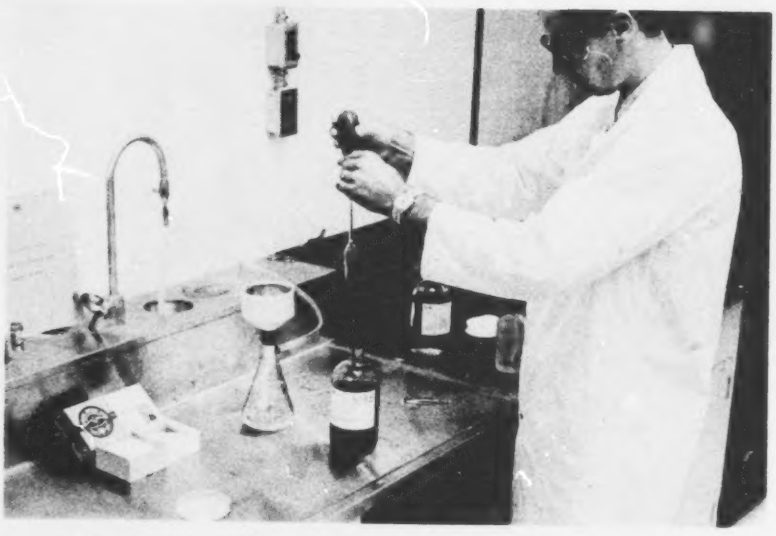

Figure 10-5
Pipet sample.

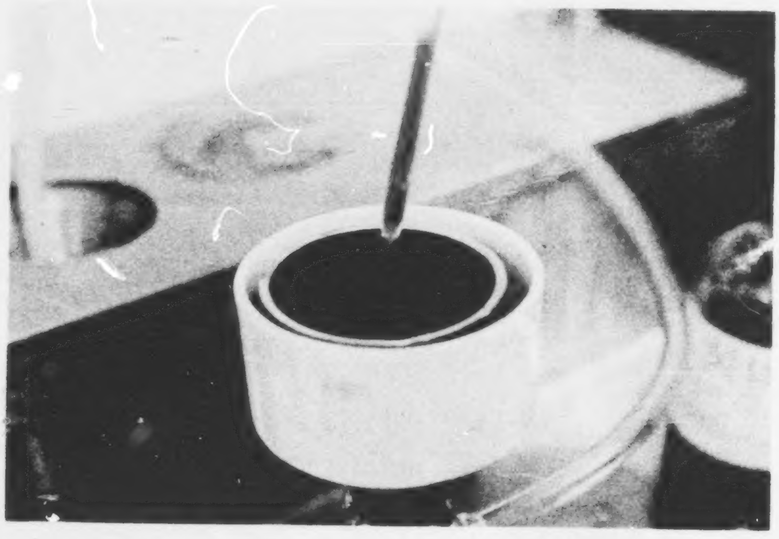

Figure 10-6
Drain pipet onto filter paper inside brass ring.

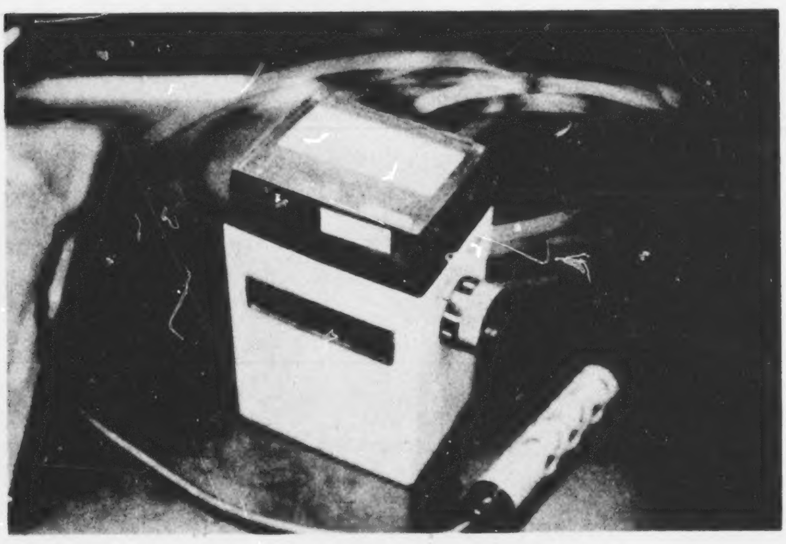

Figure 12-1 E.I.L. DO Meter & Probe
(Readout in per cent saturation)

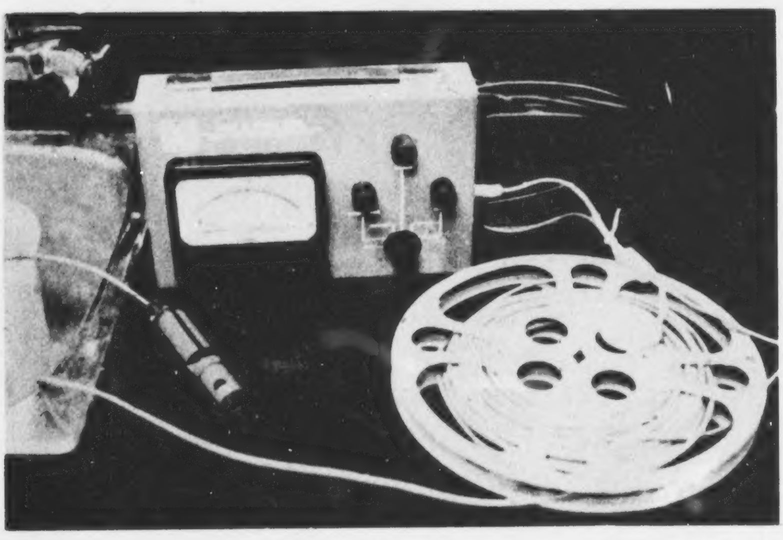

Figure 12-2 Y.S.I. DO Meter & Probe
(Readout in mg. per litre)

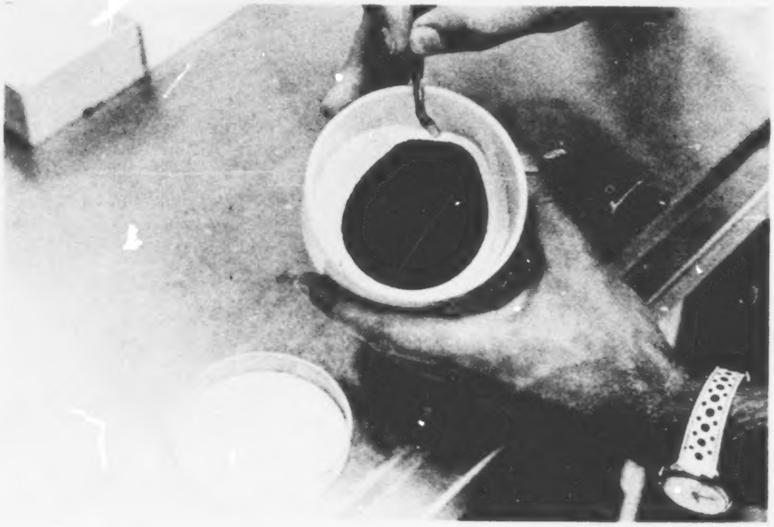

Figure 10-7

Remove glass fibre disk from Buchner Funnel.

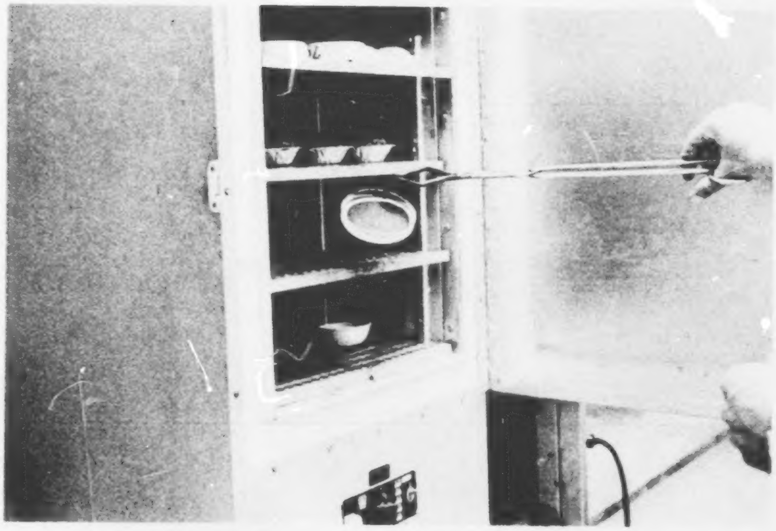

Figure 10-8

Place disk into oven.

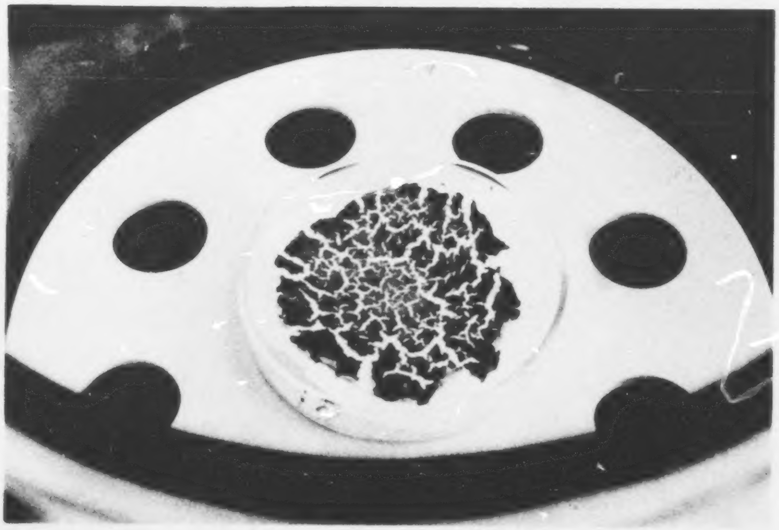

Figure 10-9

Cool disk in desiccator.

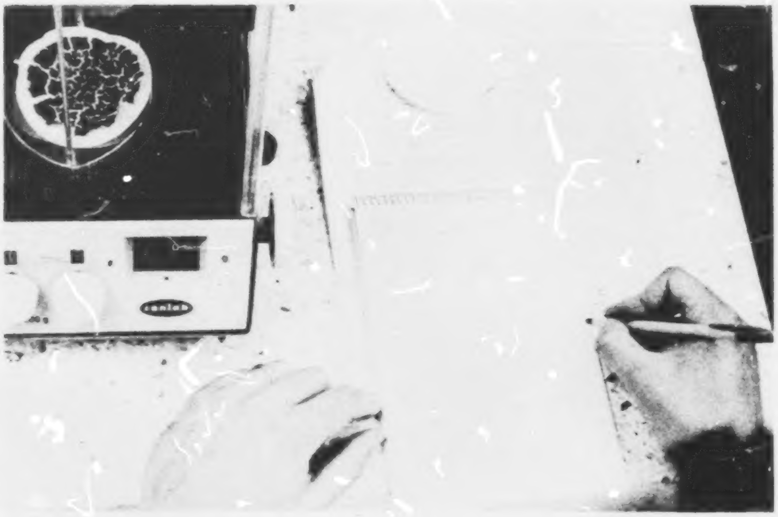

Figure 10-10

Weigh disk.

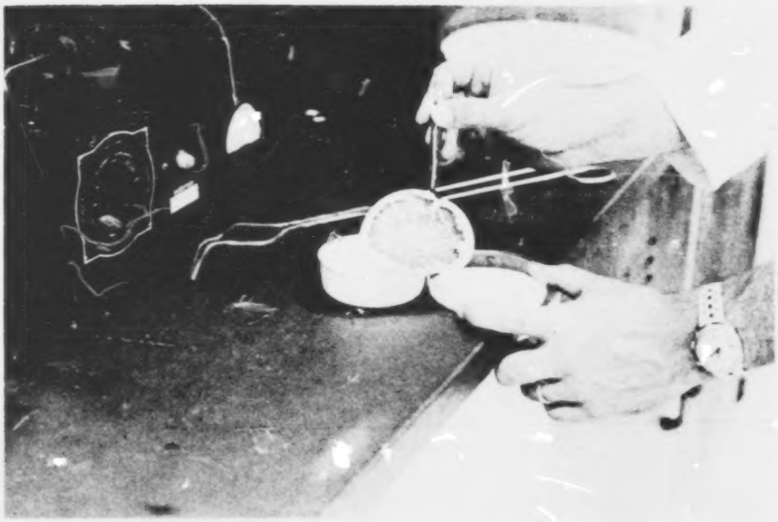

Figure 10-11

Transfer disk to porcelain dish.

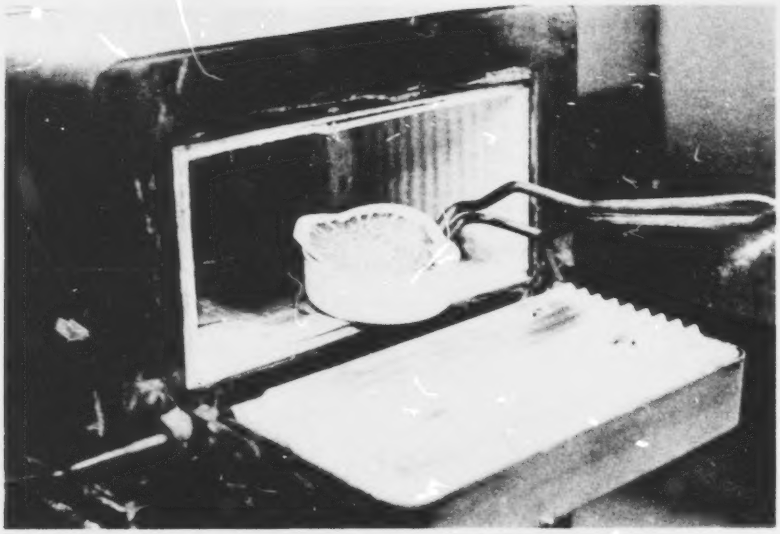

Figure 10-12

Place disk in muffle furnace.

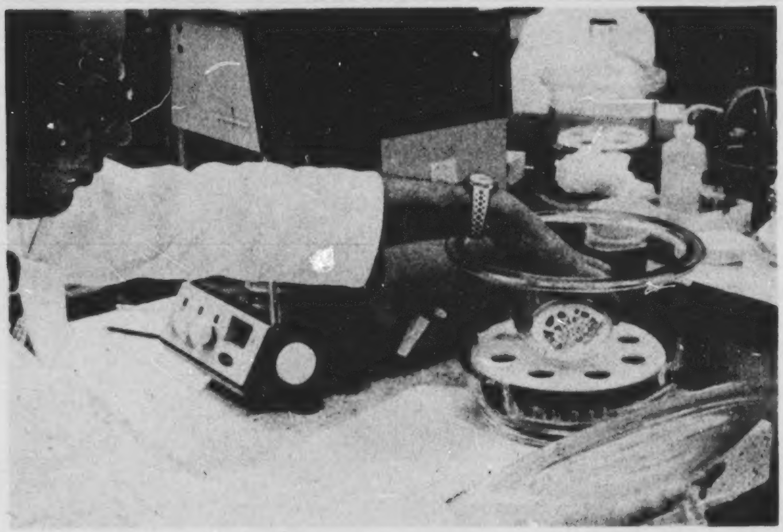

Figure 10-13 Removed cooled disk from desiccator.

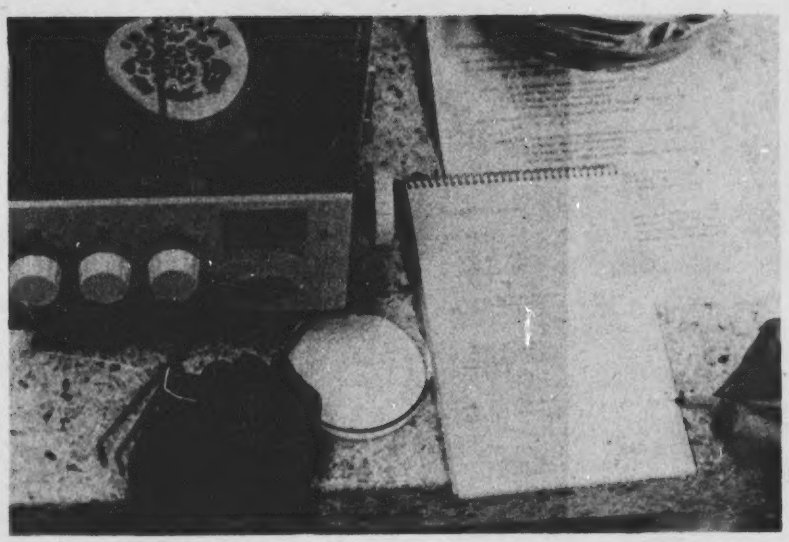

Figure 10-14 Weigh ignited disk.

c) Ignite filter disk with its suspended matter for 15 minutes at 550°C. Again using long tongs, pick up porcelain dish; transfer dish to desiccator and allow to cool for 5 minutes before totally replacing desiccator lid. Allow to cool to room temperature. (Figure 10-13)

d) Using forceps, pick up filter disk, place on analytical balance and weigh. Record this weight as the "ASHED WEIGHT". (Figure 10-14)

NOTE: The volatile suspended solids consists of the weight loss on ignition.

CALCULATION

The suspended solids and volatile suspended solids can now be determined using the following formulae:

1. To determine SUSPENDED SOLIDS (mg/l)

$$SS = \frac{(B-A) \times 1000 \times 1000}{V}$$

where SS = Suspended solids (milligrams per litre)
A = Dried Weight (grams)
B = Dried Weight + Solids (grams)
V = Volume of sample used for analysis (millilitres)

EXAMPLE

Sample volume of mixed liquor used	= 50 ml.
Dried disc weight (tare weight)	= 0.0615 gm.
Dried weight of disc and solids	= 0.2145 gm.

Calculate the MLSS in mg/l

NB. 1 gm = 1000 mg

Applying this data to the formulae for suspended solids calculation:

$$MLSS = \frac{(B-A) \times 1000}{V} \times 1000$$

where MLSS = suspended solids mg/l
A = dried disc weight (tare weight in grams)
B = dried weight of disc and solids in grams
V = volume of sample used in ml

$$\text{thus}\quad MLSS = \frac{(214.5-61.5) \times 1000}{50}\ \text{mg/l}$$

$$= \frac{153 \times 1000}{50}\ \text{mg/l}$$

$$= 3060\ \text{mg/l}$$

2. To determine VOLATILE SUSPENDED SOLIDS (mg/l)

$$SS = \frac{(B-C) \times 1000 \times 1000}{V}$$

where SS = Suspended solids (milligrams per litre)
B = Dried Weight of disc and solids (grams)
C = Ashed Weight, after burning (grams)
V = Volume of sample used for analysis (millilitres)

EXAMPLE

Sample volume of mixed liquor used	= 50 ml.
Dried weight of disc and solids	= .2145 gm.
Ashed weight, after burning	= .2099 gm.

Calculate the volatile suspended solids (mg/l)

$$VSS = \frac{(B-C) \times 1000 \times 1000}{V}$$

$$= \frac{(.2145\ \text{gm} - .2099\ \text{gm}) \times 1000 \times 1000}{50\ \text{ml}}$$

$$= \frac{(.0046) \times 1000 \times 1000}{50} = 92\ \text{mg/l}$$

SELECTION OF PROPER SAMPLE ALIQUOT

1. Raw Sewage
   Normally 50 or 100 ml aliquots are sufficient. If raw sewage is *low* in suspended solids due to run-off, wet weather conditions, or in filtration, larger sample volumes (250 ml) may be required. Non-homogenous samples may have to be blended.

2. Primary Effluent

   Normally 50 or 100 ml aliquots are sufficient. Clear-looking effluents, such as that obtained from chemical treatment, may require aliquots of 200 ml for the analysis.

3. Mixed Liquor

   Normally 50 ml aliquot is sufficient. Filamentous sludges may be difficult to filter; in exceptional cases, the sample aliquot may have to be reduced to 25 ml.

4. Return Sludge

   Normally 25 or 50 ml are sufficient. Filtration may be affected by the quantity of filamentous growth present: the more filamentous growth, the harder the filtration.

5. Final Effluent

   Normally one litre is required for crystal clear effluents. If suspended solids are easily visible, 200 or 500 ml are sufficient. During plant upsets where effluent quality has deteriorated, 100 ml or 50 ml are sufficient.

6. Digester Supernatants

   Anaerobic digester supernatant varies considerably, and with it, the ease of filterability. Normally, 50,25, or 10 ml are sufficient.

   Aerobic digester supernatant is usually very clear. Normally 200-500 ml are sufficient. However, should the supernatant quality deteriorate, the sample aliquot may have to be reduced to 100, 50 or even 25 mls.

7. Digester Sludges

   Because of the high solids concentrations found in digester sludges, a Total Solids Determination is recommended.

TABLE 10-1 SELECTION OF PROPER SAMPLE ALIQUOTS

Sampling Point	Aliquot Required (normal)	Aliquot Required (abnormal)
(a) Raw Sewage	50 or 100 ml	250 ml
(b) Primary Effluent	50 or 100 ml	200 ml
(c) Mixed Liquor	50 ml	25 ml
(d) Return Sludge	50 ml	25 ml
(e) Final Effluent	One (1) litre	200 or 500 ml
" "	" " "	100 or 50 ml
(f) Digester Supernatants		
Anaerobic digester	50, 25 or 10 ml	--
Aerobic digester	200-500 ml	100, 50 or 25 ml
(g) Digester Sludges	Total Solids Determination	--

SUBJECT:

PROCESS CONTROL

TOPIC: 11

TOTAL SOLIDS AND TOTAL VOLATILE SOLIDS TESTS

OBJECTIVES:

The trainee will be able to

1. Carry out the test to determine total solids and total volatile solids.
2. Calculate, based on test results,
    a) Total Solids
    b) Total Volatile Solids
3. Recall:
    a) The purpose of the Total Solids Test.
    b) On what it is normally carried out.
4. Define:
    a) Total Solids
    b) Volatile Solids

TOTAL SOLIDS AND VOLATILE SOLIDS TEST

GENERAL

Total solids measure the combined amount of suspended and dissolved matter in a sample. The amount is determined by weighing the residue after completely evaporating the liquid portion of a measured sample. The total solids are comprised of volatile solids (mainly organic matter of animal or plant origin), and fixed solids (mainly inorganic compounds such as mineral salts, sand and silt). Volatile solids are those solids which are lost after ignition at 550°C.

Total solids are normally used as a measure of the concentration of sludges which are difficult to filter, since the dissolved solids form an insignificant fraction of the total solids present. This test is normally done on raw and digested sludges.

APPARATUS

1. Porcelain evaporating dishes, capacity 35-50 ml or aluminum foil dishes if total solids only are desired.
2. Balance, capable of weighing at least to the nearest 0.01 gm, or trip balance and weights.
3. Drying oven at 103°C or infra red heat lamps.
4. Muffle furnace
5. Desiccator
6. Asbestos Mats

PROCEDURE FOR TOTAL SOLIDS

1. Dry the evaporating dish by ignition in a muffle furnace at 550°C for half an hour. Take the dish out of the furnace, cool for a few minutes on an asbestos mat, then put the dish in a desiccator to cool to room temperature. Slide the cover so

that the desiccator is slightly open when the dish is hot. Close completely only when the dish is nearly cooled. *Why? Leaving a hot dish in a sealed desiccator can make it impossible to remove the cover when the desiccator and contents have cooled. If foil dishes are being used, dry in the oven, not the muffle furnace.*

2. Weigh the dish to the nearest 0.01 gm and record weight as *weight of empty dish.*
3. Pour in about 25 ml of well mixed sludge sample and weigh the dish plus wet sample to the nearest 0.01 gram. *Record the weight of dish and wet sample.*
4. (a) Put the dish and sample in the oven and dry overnight. If there is no fume hood or canopy, it is best to put the sample in the oven just before going home.

   OR

   (b) Under a canopy, place the dish and sample under a heat lamp placed about 4-6 inches away. Evaporate the sample until it is almost dry, then put it in the oven for an hour.
5. Cool the dish with the dried sample in a desiccator.
6. Weigh the dried residue in the dish to the nearest 0.01 gram and record *weight of dish and dried sample.*

CALCULATION OF TOTAL SOLIDS

% Total Solids =

$$\frac{\text{Wt. of dish \& dried sample} - \text{Wt. of empty dish}}{\text{Wt. of dish \& wet sample} - \text{Wt. of empty dish}} \times 100\%$$

PROCEDURE FOR TOTAL VOLATILE SOLIDS

1. Use the dried sample obtained in determining total solids.
2. Preheat the muffle furnace to 550°C.

3. Using tongs set the dish just inside the furnace.
4. With the door open, allow the sample to burn slowly (with no flame).
5. After the sample is burned, set the dish in the furnace and close the door.
6. After five minutes or so, open the door in order to introduce oxygen and to check the sample to see if it is completely burned.
7. Close the door, and leave the dish in the furnace for about another half hour and check again. If the residue or dish has a black carbon deposit, leave it in the furnace for an extra 15 minutes and check again.
8. When there is no evidence of carbon in the ash or on the dish, remove the dish from the furnace using tongs.
9. Cool for a few minutes on an asbestos mat.
10. While still using tongs, place the dish in the desiccator, leaving the cover slightly open until the dish (and desiccator) return to about room temperature. Close the desiccator, cool to room temperature.
11. Weigh the dish plus ash to the nearest 0.01 gm and record *weight of dish and ash.*

CALCULATION OF TOTAL VOLATILE SOLIDS

% Total Volatile Solids =

$$\frac{\text{Wt. of dish \& dried sample - Wt. of dish \& ash}}{\text{Wt. of dish \& dried sample - Wt. of empty dish}} \times 100\%$$

Note: Weight of dish and dried sample and weight of empty dish were previously recorded when determining Total Solids.

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SUBJECT:

PROCESS CONTROL

TOPIC: 12

DISSOLVED OXYGEN ANALYSIS

OBJECTIVES:

The operator will be able to:

1. Demonstrate the method of DO analysis using a DO meter.
2. Calibrate a DO Meter.

DO ANALYSIS

METHODS OF ANALYSIS

The dissolved oxygen level of a sample or contents of a basin or tank can be determined by a membrane type DO meter or the chemical, modified WINKLER METHOD.

DO METERS

General

Measurement of the dissolved oxygen (DO) concentration using a DO Meter, which are now common in many plants, is a good substitute for the Sodium Azide Modification of the Winkler Method. *Use of a DO Meter offers the following advantages:*

1. DO Meters are fast and accurate.
2. Results on DO Meters are unaffected by the floc present in the water.
3. Some DO Meters give direct readings in milligrams per litre (mg/l) or parts per million (ppm) while others give direct readings in per cent saturation. Simply take the meter to the site, put the probe into the liquid to be measured, turn on the meter, allow the meter to stabilize about 1 minute, and read the scale.
4. A direct reading of the liquid temperature is possible when using some DO meters.

The disadvantages are:

1. Some gaseous reactive compounds, such as sulphides, can interfere by fouling the probe.
2. The membrane area must be cleaned after each use by rinsing with water.
3. The batteries must be kept charged for use of the meter at any time.
4. Recognition of probe failure may be difficult when caused by poisoning or puncture.

Calibration of the DO Meter and Probe

Calibration should be carried out regularly if the DO Meter is to be maintained according to the Manufacturer's Maintenance Manual accompanying the meter. *Calibration should be done at least every 2 weeks.*

ZERO CHECKING THE DO PROBE

It is advisable to check the response of the probe in a solution that contains zero DO. All membrane type DO probes become sluggish in response at DO levels of less than about 1 mg/l or 10% O_2 saturation. Some probes develop a "memory" of some low level of DO and will not readily read values less than this "memory" which can be as high as 1 mg/l.

To carry out a zero check, proceed as follows:

1. Prepare a zero DO standard solution by making up a 5% solution of sodium sulphite (Na_2SO_3) and adding a small crystal of cobalt chloride ($CoCl_2$).
2. Immerse the probe into this solution, turn the meter to read D.O., and watch the response of the meter movement. USUALLY the reading rises briefly, then drops sharply, slowing down as the needle approaches zero.
3. When the needle has stopped moving, or after 3 to 5 minutes, expose the probe to a high level of DO (e.g. air or aerated water).
4. Again, immerse the probe into the sodium sulphite solution and observe the meter response.
5. This cycling of the probe from zero DO to high DO should be repeated until the meter will easily read zero in the sodium sulphite solution.

Zero readings may not always be attainable especially with older DO sensors. Readings of 0.1 to 0.2 mg/l are acceptable in that case. Probes that do not approach a zero reading after repeated cyclings may require storing in the sodium sulphite solution overnight.

The "zero" adjust position on most DO meters is designed to electronically adjust the circuit to a simulated zero DO meter reading ...

Do not use this adjustment to set the meter reading to zero when the probe is immersed in sodium sulphite solution and the meter switch set to the "read" position.

CALIBRATION - LABORATORY PROCEDURE

After the zero check has been carried out, calibration of the meter is carried out as follows:

1. Take a sample (preferably tap water) which does not contain substances that interfere with either the probe reading or the modified Winkler Method.
2. Divide the sample into two even portions (A&B).
3. Using modified Winkler Method, measure the DO in portion (A) of the sample.
4. Using the DO Meter and probe, measure the DO in portion (B) of the sample.
5. Compare the DO values obtained in (3) and (4).
6. If the results coincide, the DO meter is calibrated.
7. If the results do not coincide, adjust the meter according to Manufacturer's specifications until it agrees with the modified Winkler Method.

Alternative Procedure for Calibration

A convenient and sufficiently accurate alternative method of calibrating the DO meter and probe is outlined for those not having access to the apparatus required to perform Winkler DO determinations.

It is sometimes difficult to perform steps (3) and (4) of the above method without altering the dissolved oxygen content by accidental aeration of one of the portions. Thus, the following alternative method of calibration may be used:

1. Take approximately 750 ml of distilled water, demineralized water, or tap water that is not excessively high in dissolved solids. Transfer this water to a clean 1 litre stoppered Erlenmeyer flask, or clean stoppered tall cylinder. The water should be at approximately room temperature.
2. Shake this water vigorously for 2 minutes to entrain as much air as possible and cause the sample to become saturated with oxygen.
3. Once saturated, this sample will keep its oxygen saturation level for some period of time unless it becomes contaminated or its temperature is allowed to change drastically.
4. Following is a list* of dissolved oxygen concentrations in mg/l attainable by air saturating a sample of water at various temperatures:

°C	°F	AIR SATURATED WATER DO mg/l
17	62.6	9.7
18	64.4	9.5
19	66.2	9.4
20	68.0	9.2
21	69.8	9.0
22	71.6	8.8
23	73.4	8.7
24	75.2	8.5
25	77.0	8.4
26	78.8	8.2
27	80.6	8.1

*Standard Method, 13th ed., page 480-1.

5. *Immerse the DO probe which has been rinsed with* tap water into the vessel containing the air saturated water, making sure that all the membrane surface and temperature sensing elements are also immersed.

6. If the probe is not fitted with a means of mechanical agitation, provide the necessary agitation by raising and lowering the probe about one inch two to three times per second, without exposing the membrane surface to the air.

   Note: The probe will not respond properly unless the sample is moving past the membrane at about 0.5 ft/sec or faster. This velocity is provided by the above means of agitation.

7. Measure the temperature of the water used for calibration and set the temperature compensator dial on the meter to the measured value. Many meters have automatic temperature compensators, which eliminate the need for this adjustment.

8. Select the proper air saturation value from the above table and while agitating the probe adjust the calibration control on the meter to the selected proper DO value.

   Note: If the meter scale is calibrated in percent oxygen saturation, rather than mg/l or ppm DO, set the meter to 100% on the scale.

9. The meter is now calibrated and ready for use. When taking measurements on a sample stream, be certain to provide the necessary velocity of sample past the probe. For example, aeration sections normally provide sufficient sample velocity, whereas final clarifiers would not.

   Note: When not in use, always keep the membrane in the tip of the probe from drying by inserting in a flask of water.

   WHY? If allowed to dry out, the probe can lose its accuracy until it is reconditioned.

DO Sample Preservation of Mixed Liquor Samples

The DO present in the aeration tank (mixed liquor) is being depleted by the continuous activity of the microorganisms. To prevent this and to ensure that a correct reading is obtained, 10 ml of copper sulphate-sulphamic acid reagent for each litre of sample should be added (as a preservative) to the sample container before taking the sample. This chemical preservative will kill the microorganisms. The copper sulphate reacts with the alkalinity in the sample, forming a copper hydroxide floc which, as it settles, helps to remove the particles of sludge in the sample. The sulphamic acid, besides killing the bacteria, acts to prevent nitrite oxidation.

To obtain and preserve a sample for DO analysis by the Winkler or Hach Method:

1. Add 10 ml of copper sulphate-sulphamic acid reagent for each litre of sample to be collected in the sampling bottle.
2. Use a *tall* bottle having a capacity of about 1 quart. An assembly such as the one shown in Figure 12-3 can be used to fill the bottle, ensuring minimum liquid-air contact.
3. Lower the sampling device into the aeration tank in such a way that it will fill without entraining air.
4. Stopper the bottle and mix well by turning it upside down 4 or 5 times.
5. Allow the solids to settle until there is 50% or more clean liquor above the sludge.
6. Siphone the clear liquor into a BOD bottle. Keep the end of the siphon tube at the bottom of the receiving bottle to avoid aerating the sample, and fill until the liquor overflows the bottle. Stopper the bottle.

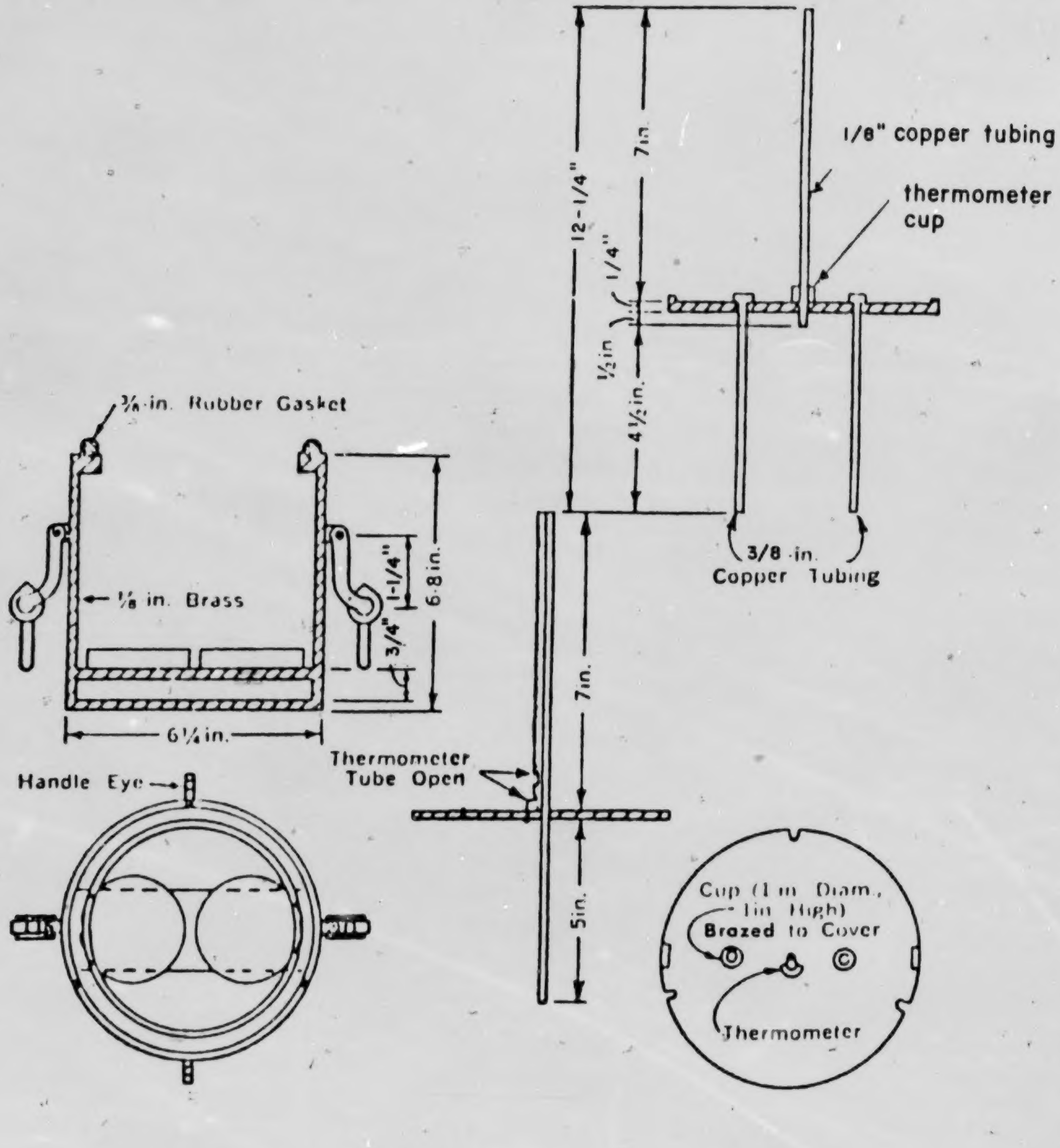

1/8" copper tubing
thermometer cup
12-1/4"
7in.
1/4"
½ in.
4½ in.
3/8 in. Copper Tubing
⅜ in. Rubber Gasket
⅛ in. Brass
1-1/4"
6.8 in.
3/4"
6¼ in.
Thermometer Tube Open
7in.
5in.
Handle Eye
Cup (1 in. Diam., 1 in. High) Brazed to Cover
Thermometer

FIGURE 12-3 DO AND BOD SAMPLER ASSEMBLY

DO NOT CREATE TURBULENCE WHEN TRANSFERRING LIQUOR INTO THE BOD BOTTLE. THIS LEADS TO AIR ENTRAINMENT.

WINKLER METHOD

The principle of the Winkler Method is that it releases iodine chemically in proportion to the amount of dissolved oxygen originally present in the sample. Using a standard solution of sodium thiosulphate as a titrant, the amount of iodine and consequently the amount of oxygen present can be determined. It should be noted that the only solution which must be accurately made up (or standardized) is the sodium thiosulphate solution. Preparation of reagents is outlined further on in this topic.

Apparatus Required

1. Buret, capacity 10, 25 or 50 ml, preferably with a Teflon stopcock.
2. Buret support and stand.
3. BOD bottles.
4. Erlenmeyer Flask (200 or 250 ml capacity).
5. Three 10 ml pipets (Serological Pipets) or three 2 ml automatic pipets.
6. One 100 ml graduated cylinder.

Procedure

1. Remove the stopper, and add 2 ml of manganous sulphate solution with the tip of the pipet *slightly below* the surface of the liquid.
2. Using a fresh pipet, add 2 ml of alkaline iodide azide solution, with the tip of the pipet *slightly below* the surface of the liquid.

NOTE: SAFETY PRECAUTIONS

(i) When transferring solutions, samples etc., by pipette from one bottle to another, use a rubber bulb or other automatic pipetter, NOT THE MOUTH.

(ii) *Use safety glasses for shielding against possible splashing.*

(iii) *Wear protective clothing (such as a lab coat, for example) to prevent damage to clothing.*

3. Make sure that no air bubbles are trapped by tapping the side of the bottle near the shoulder with the stopper. Replace the stopper.

4. Mix thoroughly by turning upside down several times. Do this over a sink since there will be liquid in the seal around the stopper.

5. Allow to settle about half-way. Mix again by inverting and allow to settle a second time. (After addition of the manganous sulphate solution and the alkaline-iodide-azide solution, the samples can be left, if necessary, to complete other work.)

NOTE: When the alkaline-azide-iodide reagent is added, a dense precipitate will form. If this precipitate is pure white, there is no oxygen present; if the precipitate is amber-coloured, there is oxygen present.

6. Remove the stopper and add 2 ml of concentrated sulphuric acid above the liquid surface, letting the acid run down inside the neck of the bottle. Use another pipet for this reagent.

7. Replace stopper and mix by inverting. Do this over a sink. The amber solution of free iodine produced is not stable and should be titrated immediately.

8. Measure 100 ml of the solution in a 100 ml graduated cylinder. Transfer it to an Erlenmeyer Flask.

9. Fill the buret to the zero mark with 0.025N sodium thiosulphate.

10. Add sodium thiosulphate from the buret at a fast rate (steady stream) while mixing the contents of the flask by swirling. Slow down the rate of titrant addition as a pale yellow colour is reached.

11. When the solution is pale yellow, add about ½ ml of starch solution (an eyedropper-full). The sample will turn blue and the titration is continued, adding the sodium thiosulphate dropwise until the solution is colourless. This is the END POINT.

    NOTE: If the colour does not appear when the starch indicator is added, the titration has been carried too far and must be repeated. If the solution turns brownish black, the starch indicator has been added too early and the procedure must be repeated.

12. Record the amount of sodium thiosulphate solution used in ml.

13. When disposing of the sample (both the titrated portion and that remaining in the BOD bottle), leave the water running in the sink to thoroughly flush the acid down the drain.

Calculation

The concentration of dissolved oxygen in the original sample is equal to *twice* the number of ml of sodium thiosulphate used when 100 ml of solution are titrated.

e.g. The titration required 2.3 ml of sodium thiosulphate solution; therefore, the dissolved oxygen concentration was 2 x 2.3 = 4.6 mg/l.

THE HACH DO KIT

This method is essentially a Winkler dissolved oxygen determination with all chemicals supplied in kit form.

1. It is a small, completely self-contained kit.
2. It is easy to transport.
3. It is easy to use (see procedure).
4. It is a modification of the Sodium Azide modification of the Winkler Test.
5. The Hach DC Kit is suited for plant applications. All the chemicals are contained in small plastic pillows, with the exception of the titrating solution. This keeps them uncontaminated and they will last a long period of time. The titrating solution, which is phenylarsene oxide, is very stable. By avoiding contamination, and keeping it well stoppered, it will remain stable for an exceptionally long period of time.

NOTE: FOLLOW THE SAMPLING AND ANALYTICAL INSTRUCTIONS CAREFULLY TO PRODUCE RESULTS COMPARABLE TO THE WINKLER METHOD.

Procedure Using the Hach DO Kit

1. Fill the DO sample bottle with the water to be tested by allowing the water to overflow the bottle for 2 or 3 volumes. Be certain there are no air bubbles in the bottle.
2. Add the contents of one Dissolved Oxygen I Powder Pillow (Manganous Sulphate) and one Dissolved Oxygen II Powder Pillow (Alkaline Iodide-Azide). Stopper in a manner to keep out air. Shake to mix and allow the floc that is formed to settle half-way in the bottle.

3. Remove the stopper and add the contents of one Dissolved Oxygen III Powder Pillow (Dry Acid). Re-stopper and shake to mix. The floc will dissolve and a yellow colour will develop if oxygen is present. *This is the prepared sample.*

4. Fill the sample measuring tube level full with prepared sample and pour it into the 1 oz. titrating vial.

5. Using the dropper provided, add PAO Solution, swirling to mix, and counting each drop. The titrating end point is reached when the sample has turned colourless. Use starch indicator if available to obtain sharper end point. The mg/l Dissolved Oxygen is equal to the number of drops used.

   NOTE: It is a bit tricky to stopper the DO sample bottle without getting an air bubble trapped in the bottle. To avoid the air bubble, tip the sample bottle slightly, and insert the stopper with a quick thrust. This will force the air bubbles out.

All the above directions are supplied with the kits and include a procedure for Low Range Dissolved Oxygen where each drop of PAO is equal to 0.2 mg/l.

PREPARATION OF REAGENTS

Copper Sulphate - Sulphamic Acid

1. Dissolved *approximately* 32 gm of technical grade sulphamic acid (NH_3SO_2OH) without heating in about 475 ml of tap or distilled water.

2. Dissolve 50 gm of technical grade copper sulphate crystals ($CuSO_4.5H_2O$) in about 400 ml of tap water.

3. Mix the two solutions.

4. Add *approximately* 25 ml of concentrated acetic acid.

Manganous Sulphate Solution

1. Weigh out about 480 gm of manganous sulphate ($MnSO_4.4H_2O$).

2. Dissolve in 400 to 600 ml of distilled water.

3. Add distilled water to make up volume to 1 litre.

   NOTE: Filtration of the solution as recommended in "Standard Methods" may be necessary if there is an oily film on top, or if there is evidence of insoluble black matter.

   The solution, using reagent grade manganous sulphate, is a clear pink colour.

Alkaline Iodide-Azide Solution

1. Weigh about 500 gm of sodium hydroxide (or about 700 gm of potassium hydroxide).

2. Dissolve the sodium hydroxide in 500 to 600 ml of distilled water in a Pyrex beaker, cooling the solution in a water or ice bath.

3. Weigh about 150 gm of potassium iodide (KI) (or 135 gm of sodium iodide, NaI).

4. Dissolve the potassium iodide in about 200 to 300 ml of distilled water. When the sodium hydroxide solution is cool, add the potassium iodide solution to it slowly while mixing.

5. Dissolve about 10 gm of sodium azide (NaN_3) in 50 ml of distilled water. *CAUTION: Sodium azide is unstable and in acidic solution could be explosive and also releases toxic fumes.*

6. Add the sodium azide solution to the cooled alkaline iodide solution.

7. Dilute with distilled water to 1 litre.

Sulphuric Acid

Use concentrated reagent grade sulphuric acid. Handle it carefully because it is a strong acid. It will "burn" holes in cloth, especially cotton, and can cause severe irritation of the skin.

NOTE: ALWAYS ADD ACID TO WATER - NEVER WATER TO ACID.

Starch "Solution"

1. Make a thin paste of 3 gm of starch (soluble, potato, arrowroot, etc.) with a small amount of distilled water.
2. Pour into 500 ml of boiling distilled water.
3. Add 1.25 gm/l of salicylic acid for preservation.
4. Allow to cool and settle overnight.
5. Decant, saving the clear supernatant.

Sodium Thiosulphate Solution (0.025N)

NOTE: 0.025N Sodium Thiosulphate Solution may be purchased from some chemical supply houses, or prepared as follows:

1. Weigh out, as accurately as possible, 6.20 gm of sodium thiosulphate crystals ($Na_2S_2O_3.5H_2O$). Do *not* dry before weighing.
2. Dissolve in distilled water and make up to 1.00 litre with distilled water.
3. Add about 5 ml chloroform or about 0.4 grams of sodium hydroxide pellets as a preservative.

   NOTE: If this solution is to be used for plant dissolved oxygen tests only, it will be sufficiently accurate. However, if it is to be used in BOD determinations, it should be standardized against 0.025N Potassium Dichromate (Reagent g). Because the sodium thiosulphate solution is unstable, *it should be replaced every month or standardized weekly if it is used for BOD's.*

Potassium Dichromate Solution (0.025N)

NOTE: 0.025N Potassium Dichromate Solution may be purchased from some chemical supply houses, or prepared as follows:

1. Put about 5 gm of reagent grade potassium dichromate ($K_2Cr_2O_7$) in a 50 ml beaker or a weighing bottle.
2. Dry the potassium dichromate at 103°C overnight in the oven.
3. Cool in desiccator.
4. Weigh out exactly 1.226 gm, transferring it to a 1 litre volumetric flask.
5. Dissolve in distilled water; make up to the 1 litre mark.
6. Transfer the solution to a reagent bottle for storage. No solutions should be stored in volumetric flasks.
7. This solution is stable and will not have to be replaced unless it becomes contaminated or is allowed to evaporate significantly.

SUBJECT:

PROCESS CONTROL

TOPIC: 13

OXYGEN UPTAKE TEST

OBJECTIVES:

The trainee will be able to

1. Recall the purpose of the Oxygen Uptake Test.
2. Define Specific Uptake Rate. (SUR)
3. Given the Oxygen Uptake Test results, calculate -
    a) Oxygen Uptake Rate
    b) Specific Uptake Rate (SUR)

OXYGEN UPTAKE TEST

Purpose

Biological waste treatment in the activated sludge process is based on the ability of micro-organisms to utilize dissolved oxygen in breaking down soluble organic substances.

The oxygen uptake test is a means of measuring the respiration rate of the organisms in the activated sludge process. Since it measures the oxygen used in the process, it is a useful tool in the evaluation of process performance, aeration equipment and biodegradability of the waste. So that comparisons can be made between various plants, it is usually expressed as the SUR (specific uptake rate); i.e. the amount of oxygen in mg utilized by one gram of the volatile suspended solids in the activated sludge, in one hour.

Equipment Required

1. Dissolved oxygen meter
2. 1 litre Erlenmeyer flask with stopper suitably bored to admit oxygen probe
3. Magnetic stirrer and magnetic stirring bar
4. 5 litre aspirator bottle or other suitable container.

Procedure for Determining the Uptake Rate

1. Using the dissolved oxygen meter measure and record the DO and temperature of the activated sludge in the aeration tank at the effluent end.
2. Take approximately 2 litre of the mixed liquor and place it in the aspirator bottle.
3. Place the Erlenmeyer flask with the magnet inside it on top of the magnetic stirrer.
4. Shake the activated sludge in the aspirator bottle vigorously for about 15 seconds and fill the Erlenmeyer flask almost to the top.
5. Place the DO probe in the flask making sure the

stopper provides a good seal and switch on the magnetic stirrer.

6. After about 1 to 2 minutes record the DO concentration in the flask every minute for approximately 10-20 minutes. The actual time required depends on the rate of oxygen depletion. Allow sufficient time to get at least 1 mg/l DO difference between start and finish of the test.
7, Plot the oxygen depletion against time on the "Oxygen Utilization Test Sheet" and calculate the uptake rate.

Calculation of Oxygen Uptake Rate (Refer to Oxygen Utilization Test Sheet, P.13-3)

1. The dissolved oxygen values recorded every minute are plotted on the graph of the Test Sheet.
2. A straight line is then drawn so that it passes through the most number of points.
3. The slope can now be calculated: two points in time are selected through which the line passes (e.g. 0 minutes and 10 minutes are used in the example sheet). The DO at these points in time is then observed (e.g. 7.4 mg/l at 0 minutes and 3.4 mg/l at 10 minutes). By subtracting the lower DO value from the higher and dividing the answer by the time interval selected, the slope is obtained.

   Thus $\frac{7.4 - 3.4}{10} = 0.4 \text{ mg } 0_2\text{/l/min.}$
4. The Uptake Rate is expressed normally in the units mg 0_2/l/hr therefore from the slope:

   $$\begin{aligned}\text{Uptake Rate} &= 0.4 \text{ mg } 0_2\text{/l/min x 60 min/hr} \\ &= 24 \text{ mg } 0_2\text{/l/hr.}\end{aligned}$$
5. The Specific Uptake Rate (SUR) can now be calculated:

$$\text{SUR} = \frac{\text{Uptake Rate x 1000}}{\text{MLVSS (ppm)}}$$

OXYGEN UTILIZATION TEST NO. 1 DATE: Sept. 1, 1976

LOCATION : Bugtown WPCP

TEST CONDITIONS: Aeration tank No.2. East Side. Initial DO 2.3 ppm

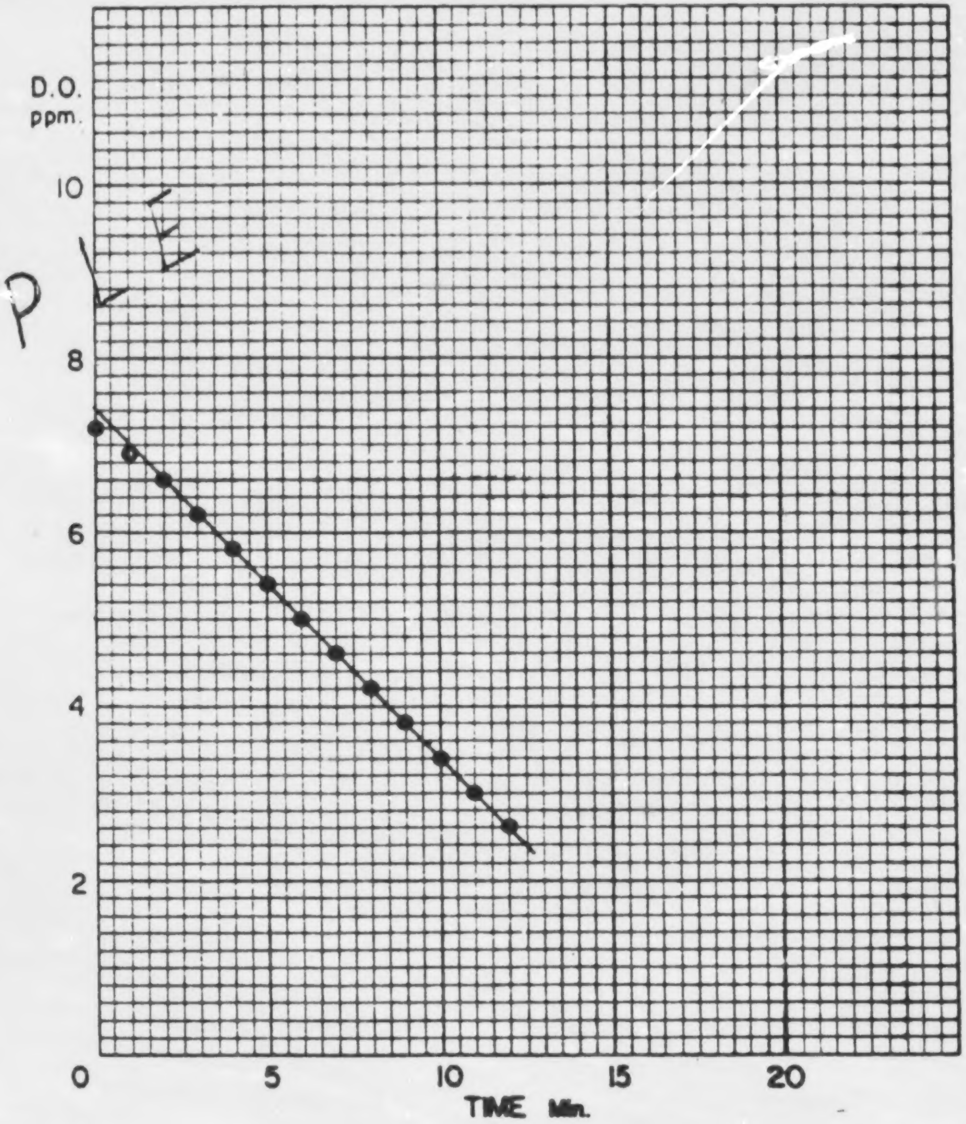
TEMPERATURE : 18°C

SLOPE : $\frac{7.4 - 3.4}{10}$ = 0.4 mg/l/min

UTILIZATION RATE : 24 mg/l/hr

EXAMPLE

TIME Start.	TIME Min	D.O. ppm.		
2.00 pm	0	7.2		
	1	6.9		
	2	6.6		
	3	6.2		
TEMP.°C	4	5.8		
	5	5.4		
	6	5.0		
	7	4.6		
18°C	8	4.2		
	9	3.8		
	10	3.4		
	11	3.0		
	12	2.6		



OXYGEN UTILIZATION TEST NO. ________ DATE: ___________

LOCATION :

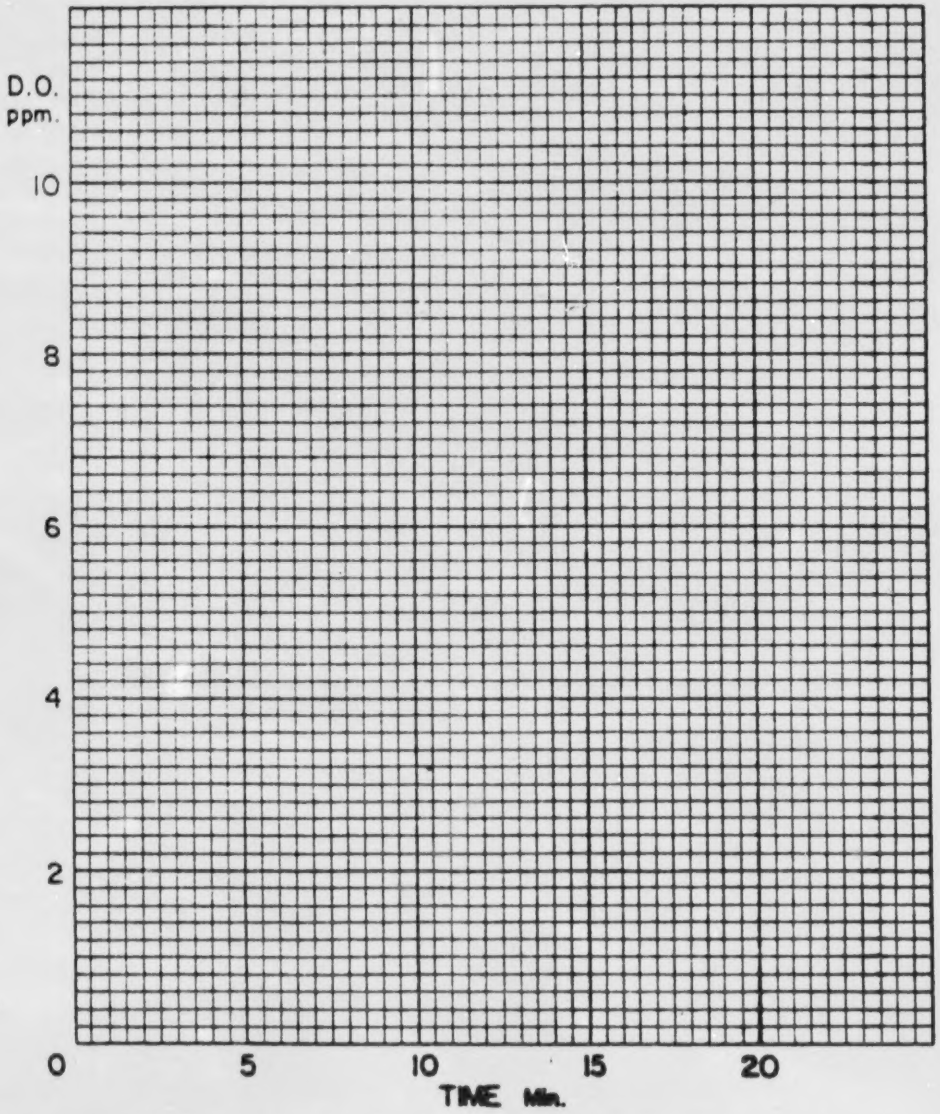
TEST CONDITIONS :

TEMPERATURE :

SLOPE :

UTILIZATION RATE :

TIME Start.	TIME Min	D.O. ppm.		
TEMP.°C				



e.g., say volatile suspended solids = 2400 ppm*
and uptake rate = 24 mg/l/hr

$$SUR = \frac{24 \times 1000}{2400} = 10 \text{ mg } O_2\text{/l/hr/g MLVSS}$$

*This figure would have been obtained from the routine daily solids analysis.

Application in Process Control

Once the operator has established the SUR for his own process he can then recognize some upsets which may occur even before the effluent quality is affected.

Example A:

Suppose that at 10:00 a.m. the DO in the aeration tanks is normally 3.4 mg/l and the SUR is 6 mg O_2/l/hr/g. However, although everything looks normal a second measurement around 3:00 p.m. shows that the DO is only 0.5 mg/l and the SUR 14 mg O_s/l/hr/g.

These conditions are indicative that an *abnormally high* organic load has entered the plant. In order to avoid poor effluent quality, the DO in the aeration tanks should be increased by employing additional blowers, or by increasing the immersion or speed of the mechanical aerators. At the same time, samples would be taken and efforts should be made to trace the origin of the abnormal organic load, to determine the type of wastes. The local office of the Ministry of the Environment should be consulted.

Substances which inhibit biological processes, usually metal wastes from industry, will cause a substantial decrease in the uptake rate and an increase in the initial DO.

Example B:

Let us consider the same plant at 10:00 a.m.; the DO is 8 mg/l and the SUR is 2 mg O_2/l/hr/g. Everything else is normal.

These conditions are indicative of a substantial *decrease* in biological activity, caused by a toxic substance which has entered the plant since the last uptake test was done, or a substantial decrease in the organic content of the sewage has occurred. This latter case is unlikely however.

Little can be done to save the effluent quality, and with low biological activity it is going to worsen rapidly. Samples of the aeration tank contents and raw sewage should be collected and all efforts should be made to trace the origin of the toxic substance such as by determining the type of wastes. The nearest office of the Ministry of the Environment should be notified so that further action can be taken.

This technique will give an operator some control and knowledge of his biological process and possibly of accidental spillages to the sewer coming from a particular company or industry. The accumulated SUR data combined with other operating data are invaluable to district staff in assessing plant performance and capability.

Other Applications

Although not of direct interest to the plant operator, the oxygen uptake test can be used further in waste treatment technology.

1. Measurement of the oxygen uptake rates in conjunction with power measurements on the aeration device efficiencies. This is known as the "Steady State Method" of aerator evaluation and is used in design and process evaluations.
2. In conjunction with laboratory or pilot scale aeration tanks, respiration rates can be used to assess the biodegradability of industrial wastes or the effect of industrial wastes on an existing system.

SUBJECT:

PROCESS CONTROL

TOPIC: 14

BOD TEST

OBJECTIVES:

The trainee will be able to

1. Recall the purpose of the BOD test.
2. Describe in general terms how BOD test is performed.

BOD TEST

GENERAL

The biochemical oxygen demand (BOD) of a wastewater effluent or polluted water is determined using the dilution technique described in the 13th edition of *Standard Methods.* The test is performed using a five day incubation period and is therefore most often referred to as the 5-day BOD or BOD_5 simply BOD.

The demand for oxygen is determined by measuring the dissolved oxygen content of a sample diluted with specially prepared water containing only mineral nutrients at a certain time and measuring the dissolved oxygen content of that same sample dilution again after five days. The difference in dissolved oxygen concentration, called depletion, is assumed to be due to the biochemical action of microorganisms on the organic nutrients available in the sample. A simple calculation involving the two measured dissolved oxygen concentrations and the known per cent dilution will yield the BOD value.

PURPOSE

The BOD values obtained are derived from analyses performed at empirical (artificial) laboratory test conditions which, over the years, have become standardized. The data obtained are most useful as indications of plant performance in its entirety or individual stages. Another application might be called wastewater characterization where unusually high or low BOD values could reflect on the presence of high "strength" wastes or wastes not biologically treatable. Regular checking of the final effluent BOD is required to ensure that effluent quality meets the objectives set by the Ministry of the Environment.

APPARATUS

Apparatus required to do the BOD determinations includes the following:

1. BOD bottles (300 ml) with ground glass stoppers (number of bottles initially 5 times the number of weekly samples)
2. Incubator, thermostatically controlled to $20^{\circ}C \pm 1^{\circ}C$
3. Graduated cylinders (2 of each):
   1,000 ml capacity, with polyethylene stopper
   250 ml capacity
4. Pipets: (widemouth type) (2 of each)
   10 ml graduated type
   25, 50, 100 ml volumetric type
5. Reagent bottles
   4 of 1-litre capacity with ground glass stoppers
   1 250-ml with ground glass stopper
   1 250-ml, polyethylene with screw cap
6. Miscellaneous:
   Selection of beakers for sample neutralization and dechlorination

   One litre volumetric flask for reagent preparation

   Optional:
   Magnetic stirring apparatus
   pH meter
   Balance for reagent preparation
7. Apparatus and reagents for DISSOLVED OXYGEN DETERMINATION (See Topic 8)
8. Vessel for preparation of BOD water. Size will depend on number of BOD tests normally performed. Vessel can be either glass or plastic.

REFERENCES

1. *Standard Methods for the Examination of Water and Wastewater* - Thirteenth Edition
2. *Simplified Laboratory Procedures for Wastewater Examination* WPCF Publication #18
3. *Methods for Chemical Analysis of Water and Wastes 1971 EPA* - WQO

REAGENT PREPARATION

Distilled Water

Water used for solutions and for preparation of dilution water must be of the highest quality, distilled from a block tin or all-glass still; it must be free of chlorine, chloramines, caustic alkalinity, organic material or acids.

Phosphate Buffer Solution

Dissolve 8.5 g potassium dihydrogen phosphate, (KH_2PO_4), 21.75 g dipotassium hydrogen phosphate (K_2HPO_4), 33.4 g disodium hydrogen phosphate heptahydrate ($Na_2HPO_4.7H_2O$), and 1.7 g ammonium chloride (NH_4Cl) in about 500 ml distilled water and dilute to 1 litre. Discard the reagent (or any of the following reagents) if there is any sign of biological growth in the stock bottle. (Available from Fisher Scientific, Reagent So-P-34).

Magnesium Sulphate Solution

Dissolve 22.5 g magnesium sulphate ($MgSO_4.7H_2O$) in distilled water and dilute to 1 litre. (Available from Fisher Scientific, Reagent So-M-109).

Calcium Chloride Solution

Dissolve 27.5 g anhydrous calcium chloride ($CaCl_2$) in distilled water and dilute to 1 litre. (Available from Fisher Scientific, Reagent So-C-10).

Ferric Chloride Solution

Dissolve 0.25 g ferric chloride ($FeCl_3.6H_2O$) in distilled water and dilute to 1 litre (Available from Fisher Scientific, Reagent So-F-97).

Acid Solutions

1 N sulphuric acid: *carefully* add 28 ml of concentrated sulphuric acid to about 500 ml distilled water with constant stirring. Dilute to 1 litre with distilled water.

Alkali Solutions

1 N sodium hydroxide: carefully add 67 ml of 50% W/W sodium hydroxide solution to about 500 ml distilled water with constant stirring. Dilute to 1 litre with distilled water and store in a polyethylene bottle.

NOTE: DO NOT USE GLASS STOPPERS IN GLASS BOTTLES WITH THIS SOLUTION.

Sodium Sulphite Solution (approximately 0.025N)

Dissolve 1.575 g anhydrous sodium sulphite (Na_2SO_3) in 1 litre distilled water. This solution is not stable and should be prepared as required.

Potassium Iodide

Crystalline KI, reagent grade.

TEST PREPARATIONS

Preparation of the BOD Dilution Water

1. Store the necessary quantity of distilled water in an incubator at 20°C overnight. For example, store 2 litres of distilled water per sample for 2 dilutions.
2. The following morning, saturate the distilled water with atmospheric oxygen by doing the following: fill 1-gallon jugs approximately 3/4 full. Shake for 3 to 4 minutes, or use a magnetic stirrer apparatus if available.
3. Add 1 ml of phosphate buffer, 1 ml of magnesium sulphate, 1 ml of calcium chloride and 1 ml of ferric chloride solution for each litre of water that is prepared. Shake vigorously for approximately 2 minutes to assure complete mixing, or use a magnetic stirrer apparatus if available.

Sample Pretreatment - pH Adjustment

1. If sample pH is ABOVE 8.5, neutralize sample by adding 1 N sulphuric acid in the following manner: Place 100 ml of sample in a 250 ml beaker. Add 1 N sulphuric acid drop by drop and mix well by using a clean glass stirring rod, or use a magnetic stirrer apparatus if available.
   RECHECK THE pH AFTER EACH DROP OF CHEMICAL ADDITION UNTIL pH IS BETWEEN 6.8 AND 7.2.

2. If sample pH is BELOW 6.0, repeat step 1 using 1 N sodium hydroxide instead of 1N sulphuric acid. RECHECK pH AFTER EACH DROP OF CHEMICAL ADDITION UNTIL pH IS BETWEEN 6.8 AND 7.2.

Sample Pretreatment - Removal of Residual Chlorine

If a sample contains residual chlorine, as in a chlorinated final effluent, dechlorinate as follows:

1. Measure out 100 ml of sample into a 250 ml Erlenmeyer flask.

2. Add 0.5 ml of concentrated sulphuric acid. Mix well by swirling.

3. Add 1 g potassium iodide. Mix well by swirling until all potassium iodide is dissolved.

4. a) If a YELLOW COLOUR develops, chlorine residual is present. Proceed to step 5.

   b) If NO YELLOW COLOUR develops, chlorine residual is not present in sample. Proceed with "Sample Dilution Technique and Incubation", page 14-7.

5. If yellow colour is present, use freshly prepared 0.025N (approx.) sodium sulphite and titrate the 100 ml sample in the Erlenmeyer flask, following the same procedure used in the WINKLER DISSOLVED OXYGEN TITRATION (see Dissolved Oxygen Determination). Use starch solution as an end-point indicator. Record the titration volume.

6. Having determined the titration volume of sodium sulphite solution required to dechlorinate 100 ml of sample, the following formula will determine the required amount of sodium sulphite solution for any volume of sample:

$$V = \frac{a \times b}{100}$$

where V = volume of titrant required to dechlorinate new sample aliquot

a = volume of sample to be dechlorinated

b = volume of sodium sulphite solution found necessary to dechlorinate 100 ml of sample

7. Allow 5 minutes before proceeding with "Sample Seeding".

Sample Seeding

Samples that have required pH adjustment or dechlorination may not contain sufficient "healthy" bacteria to start a BOD reaction. For this reason, a small volume of stale domestic raw sewage is introduced into the dilution selected for the sample to provide an inoculum of bacteria. With municipal wastewaters, seeding is normally not required.

To simplify later calculations a seed concentration of 1/10 the sample dilution is used; e.g. for a 5% sample dilution, a 0.5% seed concentration would be used.

1. Add a known percentage of seeding material (domestic raw sewage, settled overnight) to the sample dilution. (See dilution technique, page 14-7, to determine the number of sample dilution required.)
2. Apply the mathematical correction for the presence of the seed material in the sample dilution to the BOD calculation (see page 14-11).

Sample Dilution Technique and Incubation

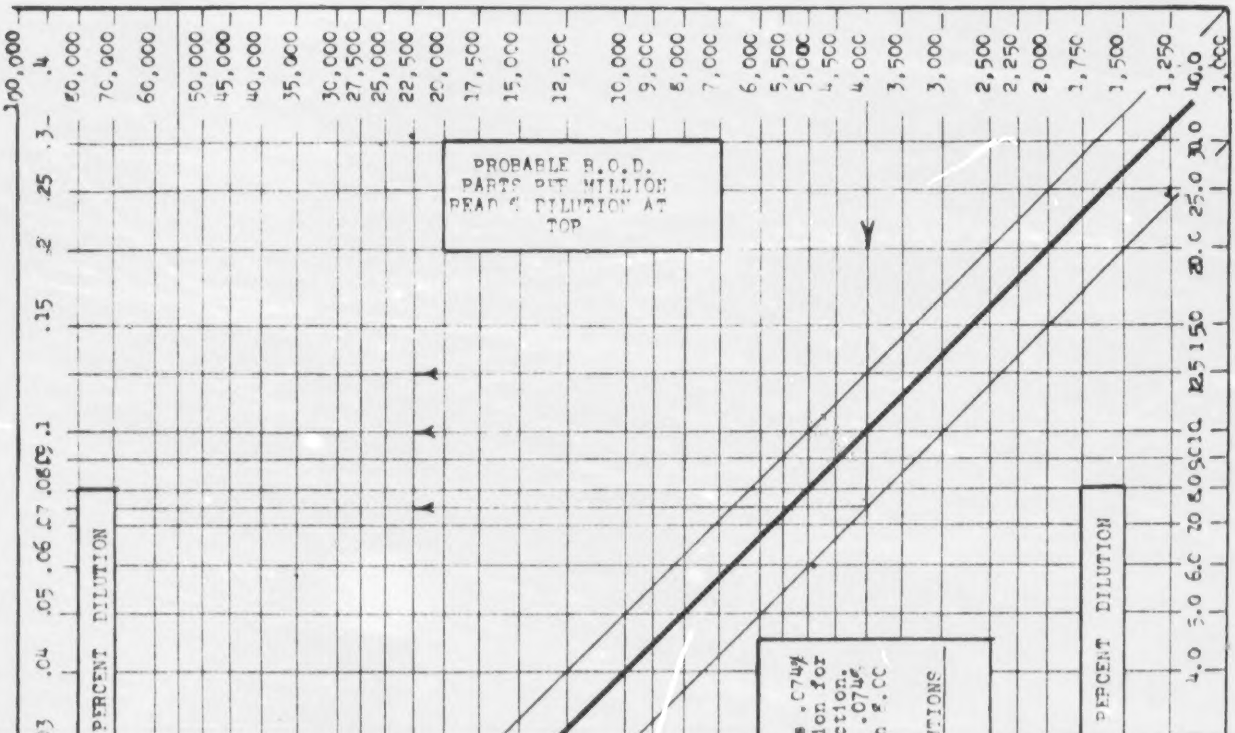
The appearance of the sample is a good indicator for estimating the best dilutions that will yield satisfactory BOD results. Those samples higher in solids will usually have a higher BOD; for example, a raw sewage composite sample normally has a higher BOD than the corresponding primary effluent composite sample. Final effluents that are low in suspended solids (15 mg/l or less) are reasonably free of turbidity and will usually have low BOD values of 15 mg/l or less . In domestic sewage, the major contribution of the BOD is caused by particulate suspended organic matter and a lesser portion is contributed by dissolved organic matter. The suspended solids concentration is therefore often a good guideline for estimating the proper dilutions in the BOD test.

1. For each sample, prepare 2 bottles for dilution; if the sample is unknown, prepare at least 3 bottles for dilution.
    a) If using the Winkler Method for the dissolved oxygen determination, prepare 2 bottles for each sample dilution, one for immediate dissolved oxygen determination, the other one for dissolved oxygen determination after 5 days of incubation.
    b) If a dissolved oxygen meter is used for dissolved oxygen determination, prepare only one bottle for each dilution.
2. The following table of BOD ranges can be useful in arriving at proper BOD dilutions along with the nomograph (Figure 14-1) on page 14-8.

TABLE 14-1 - BOD RANGE vs TYPE OF WASTE

Type of Waste	BOD RANGE (mg/l)		
	weak	medium	strong
raw sewage	50-100	150-250	250-400 or more
primary effluent	35-70	100-200	200-300
final effluent	good	poor	very poor
	less than 5-15	15-50	greater than 50

NOMOGRAPH FOR DETERMINING PROPER DILUTION IN THE B.O.D. TEST



Ex. A probable B.O.D. of 4000 ppm requires .074% dilution for 40% reduction, .1% dilution for 50% reduction, and .125% for 70% reduction. Hence dilutions should be made within .074% to .125%. Based on 50% reduction with 8.00 ppm D.O. dilution water.

NOMOGRAPH FOR DETERMINING B.O.D. SOLUTIONS

J.R. Wolfe 1949 ODH

In making the Biochemical Oxygen Demand Test it is desirable to make up the dilution of the sample so that not **more than 70% nor less than 40% of the dissolved oxygen in the diluted sample will be used up** during the incubation period of 5 days. As an aid in choosing the proper dilutions for the 5-day B.O.D. Test the above nomograph has been developed by John R. Wolfe, Ass't. Engr., Ohio State Dept. of Health.

Example Using Nomograph

Suppose the raw sewage is of medium "strength" as determined by visual inspection and possibly from a suspended solids analysis. The BOD is estimated to be around 200. According to the nomograph, a BOD of 200 requires a dilution of 2%. Follow the line at 200 across to the thick black line, then follow the intersected line to arrive at 2.0 per cent dilution. The line at 2% crosses the two thin black lines of the graph at BOD values of 150 and 250. This means a 2% dilution can be used reliably for a BOD range of 150 to 250. To protect against errors in BOD estimation, one or two more dilutions should be set up to take care of unexpected high or low values. This is also a good way to double check the result obtained for the first dilution. Dilutions of 1.25% and 3% would cover the BOD range from 100 to 400 and setting up these additional dilutions is recommended in this case.

PROCEDURE FOR TEST

1. Neutralize and/or dechlorinate an aliquot of the sample requiring BOD determination.
2. For each pretreated sample select at least two dilutions using the Table 14-1 and accompanying nomograph.
3. For each sample dilution chosen, label two clean BOD bottles for Winkler Dissolved Oxygen Method or one BOD bottle for dissolved oxygen meter method. The label should identify the sample, the per cent dilution chosen and the date on which the sample is to be removed from the incubator.

   To simplify the preparation of the dilutions and to minimize errors *always prepare one litre of sample dilution, discarding the unused portion.*
4. Using a volumetric pipet for volumes up to 100 ml, or a graduated cylinder for volumes larger than 100 ml, add the selected sample aliquot to a 1,000 ml graduated cylinder that is fitted with a polyethylene stopper. Add BOD dilution water to the

1,000 ml mark. Stopper the cylinder and turn it upside down slowly four or five times to mix the contents. Remove the stopper and completely fill two properly labelled BOD bottles with the sample dilution by pouring it slowly down the inside neck of each bottle held slightly tipped, just as one would pour beer into a glass to prevent foaming. Discard the unused portion of the sample dilution.

5. Prepare a second and third (if required) dilution of the same sample as in above.

6. Wait 15 minutes after filling the BOD bottles with sample before stoppering them. WHY? To allow any bubbles to rise to the top of the bottle. Bubbles seen settling on the inside shoulder of the bottle should be removed by grasping the bottle by its neck and gently tapping the outside shoulder of the bottle with the glass stopper.

7. Stopper the bottles with the glass stoppers. Avoid entrapment of air by inclining the bottle slightly and inserting the stopper with a quick motion.

8. a) Using the Winkler Method, determine the dissolved oxygen concentration on one bottle of each sample dilution that has been prepared as soon as the bottles have been stoppered. Place the other dilution bottles in an air incubator for five days at 20°C ± 1°C (68°F ± 2°F).

   b) *If dissolved oxygen meter with BOD bottle probe is used*, only one bottle of each sample dilution is prepared. In this case, the dissolved oxygen content is determined as soon as the sample dilution is ready to be stoppered. After the dissolved oxygen content has been determined and recorded, the bottle is stoppered, taking care to prevent entrapment of air bubbles. The bottle is then incubated for five days at 20°C ± 1°C and the oxygen content redetermined.

9. Dilutions showing a residual dissolved oxygen concentration of at least 1 mg/l and a depletion of at least 2 mg/l should be considered the most reliable. The precision of the test is about ± 20%. This means that for a sample having a BOD of 200, the test may show results as high as 240 or as low as 160. Keep this in mind when relatively poor correlation is found in a particular test series. Averaging of the most reliable results obtained in the test on a particular sample may be used.

CALCULATIONS

$$\text{mg/l BOD} = \frac{(D_1 - D_2) \times 100}{d}$$

where D_1 = dissolved oxygen content (mg/l) of sample dilution 15 minutes after preparation.

D_2 = dissolved oxygen content (mg/l) of sample dilution after 5-day incubation.

d = per cent dilution of the sample used.

Where the sample has been seeded, the following formula is used:

$$\text{mg/l BOD} = \left[(D_1 - D_2) - (S_1 - S_2)f\right] \times 100$$

where D_1 = dissolved oxygen content (mg/l) of sample dilution 15 minutes after preparation.

D_2 = dissolved oxygen content (mg/l) of sample dilution after 5-day incubation.

S_1 = dissolved oxygen content of seed control dilution 15 minutes after preparation.

S_2 = dissolved oxygen content of seed control after 5- day incubation.

f = ratio of % seed used in sample (D_1) to % seed used in control (S_1).

EXAMPLE 1

A raw sewage sample BOD determination was performed using dilutions of 1%, 2% and 5%. The following results were found:

d	D_1	D_2	$D_1 - D_2$	
1%	8.4	6.0	2.4	$\frac{2.4 \times 100}{1} = 240$
2%	8.3	4.2	4.1	$\frac{4.1 \times 100}{2} = 205$
5%	8.2	0.4	7.8	$\frac{7.8 \times 100}{5} = 156$

The 1% and 2% dilution show depletions ($D_1 - D_2$) of more than 2 mg/l and residual dissolved oxygen levels (D_2) of more than 1 mg/l. The 5% dilution shows a residual dissolved oxygen level of less than 1 mg/l, making the result unreliable and it should not be used. The other two results which are calculated to be 240 and 205 are reliable. The average of the two results to 222.5. This number should be rounded off to 220 when reporting the result.

EXAMPLE 2

A sample of chlorinated final effluent was dechlorinated using the prescribed method and stale raw sewage was used to seed the sample.

The sample was seeded with 0.3% of stale sewage and the seed control was incubated at 3% concentration. The following results were found on a 25% seeded sample dilution and the seed control.

D_1 = 8.3 ppm D.O.

D_2 = 4.5 ppm D.O.

S_1 = 8.0 ppm D.O.

S_2 = 3.1 ppm D.O.

Enter these results in the BOD equation:

$$\text{mg/l BOD} = \frac{(8.3 - 4.5) - (8.0 - 3.1)\ \frac{0.3}{3}}{0.01 \times 25}$$

$$= \frac{(3.8) - (4.9)\ 0.1}{0.25}$$

$$= \frac{3.8 - 0.49}{0.25}$$

$$= \frac{3.31}{0.25}$$

$$= 13.2$$

The result is reported as 13 mg/l.

253

SUBJECT:

PROCESS CONTROL

TOPIC: 15

pH MEASUREMENT

OBJECTIVES:

Using a pH Meter (Electrometric Method), trainees will be able to:

1. Standardize the pH Meter.
2. Take the pH reading of a sample.
3. Maintain electrodes in operating condition.

pH MEASUREMENT

pH

pH is a term that is used to express the level or intensity of the acid or alkaline conditions that prevail in a sample. Technically speaking pH is a measure of the hydrogen ion concentration in solution. Theory shows that in aqueous (= water based) solutions this hydrogen ion concentration ranges from a high of 1.0 mole/l down to 0.000 000 000 000 01 mole/l. Since the International System of Atomic Weights established 1 mole of hydrogen to weigh 1 gram this concentration range could be looked upon as 1.0 g/l to 0.000 000 000 000 01 g/l. Figures of this order are not well suited for practical applications and the Danish technician Sorenson suggested a now universally accepted method of expressing the hydrogen ion concentration using logarithms. The above concentrations are nearly always less than 1 mole/l or 1 g/l and the logarithm would nearly always be negative. Sorenson thus used the symbol p in front of the chemical symbol H (for hydrogen) to change the sign of the logarithmic value to positive and called his scale "pH values". For aqueous solutions the scale ranges from 0 to 14 with 7 being the neutral point where a sample is neither acidic, nor alkaline.

Strong Acid   Weak Acid   Neutral Point   Weak Alkali   Strong Alkali

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

pH scale

Measurement of pH is accomplished by means of pH electrodes which develop a potential (voltage) which can be measured by a suitable amplifier (pH meter). In essence these electrodes constitute a cell (battery) whose output potential (voltage) is governed by the pH value of the test solution.

METHODS OF MEASUREMENT

pH Indicators and Indicator Papers

There is on the market a large variety of pH indicators for use with comparators or photometers. Indicator papers for pH are available covering various narrow or wide ranges of pH.

This method of measurement is very useful when an approximate spot check of the pH of a particular waste stream becomes necessary either at a plant or in a sewer system. It must be noted that pH indicators or indicator papers are affected to various extents by the following sample parameters: dissolved solids, colloids, suspended solids, protein, O.R.P. and solvents. If pH readings accurate to 0.1 pH units are desired, the electrometric method should be used.

Electrometric

1. Principle of Operation

   A measurement is made of the millivoltage that is produced, when a sample and a couple of electrodes of a special type are set up as a galvanic cell. The number of millivolts produced depends on the level of acidity in the cell system.

2. Types of Meters

   Several varieties of pH meters are in use. (See Figure 8-1). The basic method for the operation of such instruments is outlined on the following pages.

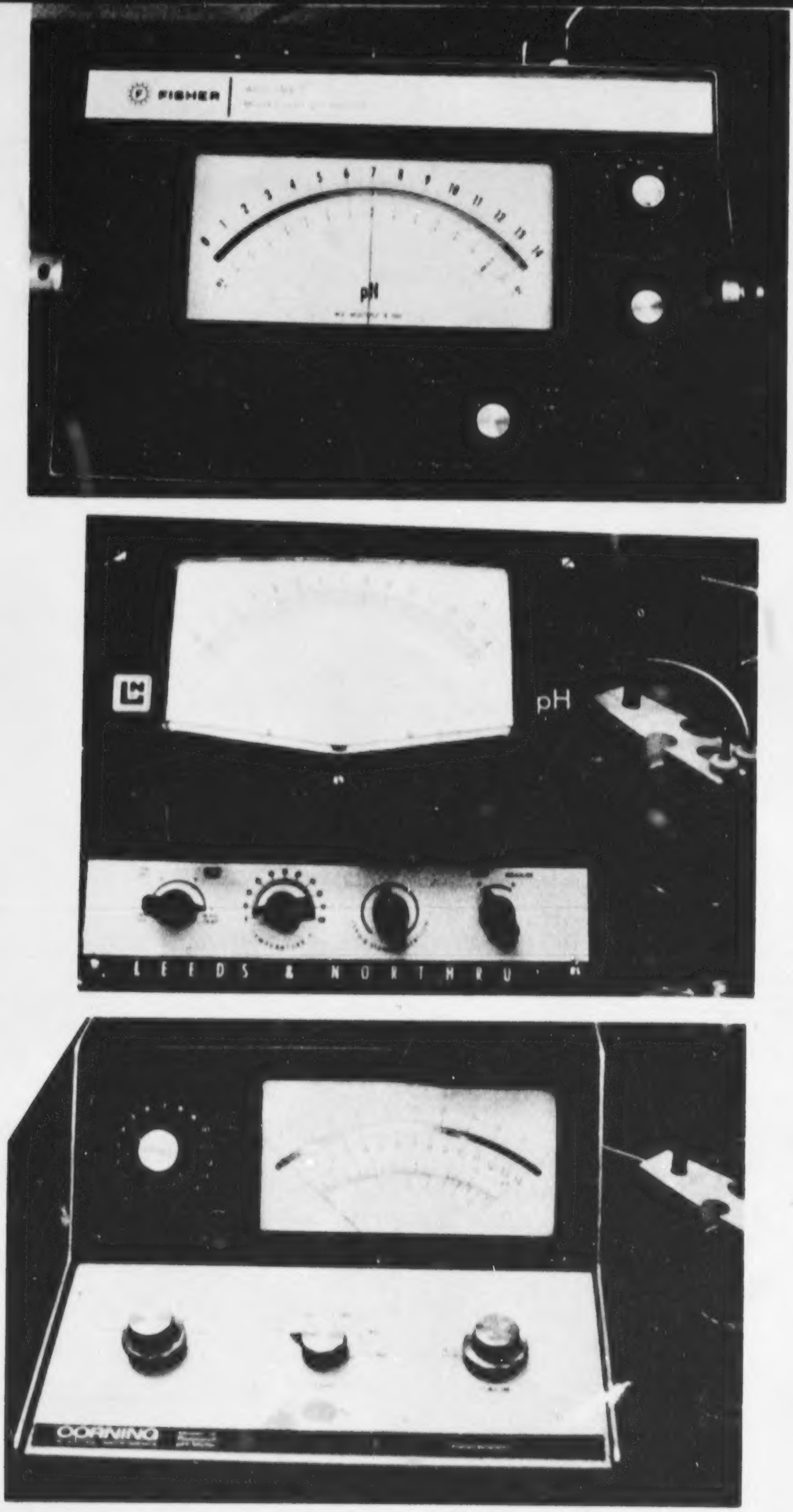

FISHER
pH
pH
LEEDS & NORTHRUP
CORNING

Figure 15-1 pH METERS

Procedure for Standardizing pH Meter

1. With the switch to the "OFF" position, plug the instrument into an A.C. receptacle of correct voltage. If the instrument is battery operated, check the batteries once monthly (or more often if the instrument is used frequently).
2. Plug the electrodes into the jacks provided.
3. If the electrodes are new, place them in distilled water overnight. -

   CAUTION: Support electrodes properly, so they do not come in contact with the beaker (use plastic beakers wherever possible).

4. Turn the instrument to "CHECK" or "STANDBY" position and allow to warm up for 3 to 5 minutes.
5. Carefully remove the electrodes from the beaker they were stored in and rinse them with distilled water.

   NOTE: (a) If the reference electrode is fitted with a rubber plug or sleeve, be certain to expose the filler vent hole to the atmosphere by removing the plug or sliding the sleeve away from the hole.

   (b) A drop of distilled water remaining on the tip of the electrodes does not matter.

6. Fill a separate plastic beaker (100-250 ml volume) with buffer solution, pH 7.00.
7. Measure the temperature of the buffer solution and set the temperature compensator to the temperature of the buffer solution.
8. Immerse the electrodes into the beaker, swirl the beaker carefully without touching the electrodes to the beaker sidewalls.

9. Turn the instrument to "READ" and watch the needle: It should deflect quickly towards the pH value of the buffer solution. The response may slow down when the needle is in within 0.2 pH units from the expected reading, but the needle should give a steady reading after about 30 seconds.
10. If the reading does not correspond with the buffer value, adjust the "STANDARDIZATION" or "BUFFER ADJUST" control to position the needle at the correct buffer value.
11. Turn the instrument back to "STANDBY", remove the electrodes from the buffer solution and rinse them off with distilled water.
12. As a quality check, to assure that the meter and probe respond to pH repeat steps 6, 7, 8 and 9, using a buffer solution of a pH value at least 2 pH units away from the first, a buffer 4.00 solution, for example.

   NOTE: *Electrodes tend to respond slower at pH values above pH 7.00, so allow 1 minute before taking a final reading if pH is above 7.00.*

13. The second buffer reading should be within 0.2 pH units from the expected value. The meter is now calibrated. Turn the instrument back to "STANDBY".
14. Recalibrate the meter daily.

Taking a Reading

1. Repeat steps 5, 6, 7, 8 and 9, using sample instead of buffer.

   NOTE: *The temperature compensator must be adjusted to the temperature of the sample and time allowed for the electrodes to reach the same temperature as the sample; for example, if the buffer temperature is 22°C and the sample tempera-*

ture only $8^{o}C$, allow 3-5 minutes for temperature equalization before taking the final reading.

2. Turn the instrument back to "STANDBY", remove the electrodes from the beaker, rinse them well with distilled water and store them in distilled water. Turn the instrument off if it is no longer used.

   NOTE: Solids adhering to the electrodes from samples such as digester samples should be removable by rinsing. Absorbent tissue such as Kimwipes or Kleenex may be used with caution to remove solids that are not removed by rinsing. DO NOT USE PAPER TOWELS!

GENERAL NOTES ON pH METERS AND ELECTRODES

1. Newer solid state (transitorized) pH meters require less warm-up time than the now outmoded tube-type meters. Tube-type meters are best kept turned on in the "STANDBY" position, unless the manufacturer suggests otherwise.
2. The meters are usually sensitive and should not be jarred, for example, when being transported.
3. Although the better meter types are static-proofed, all meters can be affected by static electricity, especially in dry weather. If the needle seems to "stick" in a certain position, breathe on the meter face to put a haze on it. If static electricity was "pinning" the needle, it should now become free. Application of an anti-static agent available as liquid or spray in electronics outlets or better record stores will cure this nuisance problem.
4. Electrodes are available as separate glass and reference electrodes or in single assemblies known as combination electrodes. For pH work,

both are equally effective, the combination type being more convenient to use since the glass and reference electrodes are packaged into one assembly. Rugged plastic bodied electrodes with protectors for the fragile pH glass bulb are available.

5. The bulb of the glass electrode is constructed of a glass membrane, a few thousandths of an inch in thickness. This makes the bulb extremely fragile and vulnerable. *Scratches on this glass caused by sliding the electrode on the inside wall of a glass beaker can affect pH readings.* When placing the electrode flat on a table, always place the bulb on a soft cloth, sponge, or absorbent tissue.
6. The reference electrodes are normally rugged enough to withstand minor shock and abrasion, but they are also made of relatively thin glass. Keep the electrolyte level high and above the level of the liquid in the beaker. If a pipet or eye-dropper seems inadequate to refill the electrolyte, use a syringe reserved for that purpose. Allowing the electrolyte to dry out can cause permanent electrode failure. A recent development to overcome such problems are sealed gel-filled reference electrodes.
7. After varying periods of usage, the electrodes will become coated with grease from sewage, hardness films from water or final effluents, or caked-on solids from digester samples. NEVER USE HOT WATER TO CLEAN EITHER ELECTRODE. Try immersing the electrodes for a few seconds in a solution having 1 part concentrated hydrochloric acid, and 1 part distilled water to remove film and "caked-on" solids; then rinse well with distilled water. Grease may be removed by wiping the pH electrode bulb with a cloth or tissue soaked with acetone, methyl alcohol or isopropyl

alcohol (rubbing alcohol), then rinsing with lukewarm tap water and replacing in the distilled water beaker. Varsol may be used if none of the other cleaning solutions are available.

8. Buffer solutions can be made up according to "Procedures in Standard Methods", but commercially available buffers, either as a dry salt, concentrate, or ready-to-use solution, are preferable when the quantity used is considered. Buffers should be stored in a dark place, such as in the drawer of a laboratory bench or in a BOD incubator. Exposure to bright sunlight or heat causes rapid decomposition of the buffer by accelerating bacterial and algal growth. Buffers are stable *for a few months (not years)* under optimum conditions, and should be purchased or prepared frequently in small amounts. Some commercially-prepared buffer solutions are labelled with an expiry date and should be discarded after this date.

9. The electrical output of a pH electrode is extremely small: about 0.004 microamperes maximum at room temperatures. Touching the plug or getting it wet may be enough to "short circuit" the electrode. For this reason the contacts on the glass electrode plug should be kept clean by wiping, if necessary, with a clean dry cloth. Tarnished silver contacts should be wiped bright with "Crocus Cloth" or 600 emery or carborundum paper.

10. Failure of the electrodes to produce readings that are within 0.3 to 0.4 of each other in the two buffer standardization techniques previously described, usually signifies defective electrodes.

SUBJECT:

PROCESS CONTROL

TOPIC: 16

VOLATILE ACID TEST

ALKALINITY TEST

OBJECTIVES:

The trainee will be able to:

1. Demonstrate the test for Volatile Acids in Digesting Sludge
2. Calculate in mg/l the Volatile Acids in Digesting Sludge
3. Demonstrate the test for determining the alkalinity of sludge
4. Calculate the alkalinity of sludge as mg/l calcium carbonate

VOLATILE ACIDS TEST

General

Low molecular weight organic acids which are readily distilled from aqueous solution at low temperature are commonly called volatile. They include acetic, propionic and butyric acids as well as small amounts of valeric, isovaleric and caproic acids. These volatile acids are formed as intermediates during the anaerobic degradation of carbohydrates, proteins and fats in sludge treatment processes. An excess accumulation of these acids can have a disastrous effect upon anaerobic digestion if the buffering capacity of the system is exceeded and the pH falls to unfavourable levels. In routine operation of an anaerobic waste treatment system, the volatile acid concentration is primarily used as the determining and controlling factor for maintaining a satisfactory balance between saprophytic and methane producing bacteria which are largely responsible for the efficiency of anaerobic digestion.

For control purposes the following short method is used in our lab. It is the direct distillation method and is quite empirical. It is not intended for accurate work. A factor of 0.7 is used to represent the amount of acid in the distillate.

Apparatus

Centrifuge

Distillation apparatus:

a) 500 ml. or 1 litre distillation flask;
b) Vertical Graham type or preferably 30 in. Liebig condenser;
c) Marble chips (Anti Bumping).

Adapter tube or trap:

Heat source - Bunsen burner or controlled electrical heater

Burette - 50 ml. plus stand

Erlenmeyer Flask - 250 ml.

Pipettes - 5 ml.

Reagents

Sulphuric acid Conc.

Standard Sodium Hydroxide Titrant 0.01 Normal
Phenol(phtha)lein indicator solution.

Procedure

Centrifuge approximately 60 mls of sample.
Pipette 50 ml of the centrifuged sample into a 1 litre distallation flask and dilute to approximately 200 mls with distilled water.

Add 2.5 mls conc. sulphuric acid making sure not to touch the neck of the flask with the acid. Immediately stopper and without delay start distillation. Distill slowly at the beginning and adjust bunsen flame making sure no carryover takes place. When distillation has begun, adjust heat to provide 3-5 ml/min. distillation rate. Heat source must be carefully controlled. Distill 150 mls into a 200 ml measuring cylinder. When the distillation is complete, check distillate with Barium Chloride. Should Barium Sulphate precipitate, start whole procedure again.

Titrate the distillate with 0.01 N sodium hydroxide using phenophthalein as an indicator. The end point is the first pink colouration that persists upon standing for a short time (Approx. 30 seconds).

Calculation

mg/l volatile acids as acetic acid

$$\frac{\text{ml. .01N NaOH} \times 6000}{\text{sample size} \times \text{concentration factor} \times 0.7}$$

Example $\frac{6.3 \times 6000}{50 \times 10 \times .7} = \frac{37800}{350} = 108$ mg/l. [Volatile Acids as Acetic Acid]

NOTE:

NaOH is available in plastic bottles to make a 1 normal solution. i.e. In a 1000ml. volumetric flask, put approximately 500ml. CO_2 free distilled water. Add 1 bottle of N/1 Sodium Hydroxide. When cool make up to the mark with CO_2 free water. To make CO_2 free distilled water, boil and cool distilled or de-ionized water keep covered. Sodium Hydroxide solutions should be kept in polyethylene bottles tightly stoppered.

ALKALINITY TEST

GENERAL

The alkalinity of sludges is determined on the liquor that may be separated by centrifugation or that liquor which will separate on standing. If a centrifuge is used, about 60 mls of centrate will be required. If settling is used, it is preferable that an Imhoff cone, 1 litre capacity, be used. The sludge should be allowed to stand until 50 mls can be withdrawn.

Supernatant liquor is usually the best source of a sample. It is considered to have all the components that need to be measured in solution. It is usually easily obtainable either from a sampling line or from an overflow box or chamber.

The important point is that all tests, pH, Alkalinity and Volatile Acids, be done on the same sample.

The titrating solution is a standard sulphuric acid and the results are expressed in mg/l Calcium Carbonate.

Two methods are presented here:

1. The potentiometric method where a pH meter is available.
2. The methyl orange colorimetric method which uses a colour change from orange to pink as the end paint.

THE POTENTIOMETRIC METHOD

Apparatus

Any pH meter with a glass electrode
Burette
Appropriate size beakers
Pipettes
Buffer solution, pH 4 and 9
Standard sulphuric acid

Method

Standard pH meter using buffer solution pH 4 and 9. Pipette a suitable aliquot of sample into a beaker. Titrate sample with standard sulphuric acid to pH 8.3 for phenolphthalein alkalinity and to pH 4.5 for total alkalinity. Results for alkalinity are reported as mg/l $CaCO_3$.

Calculation

$$\text{mg/l } CaCO_3 = \frac{\text{ml of titrant x N of titrant x 50,000}}{\text{ml of sample}}$$

THE COLORIMETRIC METHOD

Apparatus

Centrifuge with six or eight place head or Imhoff cones with stands.

Burette - 50 ml capacity with white porcelain base.

250 ml erlenmeyer flasks.

50 ml pipettes

Rubber bulbs for pipettes

Reagents

0.1 normal sulphuric acid. This is better purchased in ampoules or plastic bottles. It can be bought in such concentrations that the contents of an ampoule or bottle made up to 1 litre provides an H_2SO_4 solution of exactly 0.1 normal.

Methyl Orange indicator. Dissolve 0.5 gm methyl orange in 1 litre of distilled water.

Procedure

If a centrifuge is available, collect 60 mls of centrate in a small beaker or erlenmeyer flask. Pipette 50 ml into a 250 ml erlenmeyer. Add 50 ml of distilled or deionized water. Add 0.1 ml of Methyl Orange indicator. Note - exact volume of indicator for this titration is not critical.

Titrate with the 0.1 N H_2SO_4 to a colour change from orange to pink. The titration should be carried out over a good white surface. This will make it easier to see the colour change.

Record the ml or H_2SO_4 used.

Calculation

$$\frac{\text{mls of } H_2SO_4 \text{ x normality x } 50{,}000}{\text{ml of sample}}$$

Example: 24.3 mls of 0.1 N H_2SO_4 used.

Therefore:

$$\frac{\overset{(ml)}{24.3} \text{ x} \overset{(N)}{.1} \text{ x } 50{,}000}{50 \text{ ml of sample}}$$

$$\text{mg/l Alk as } CaCO_3 = \frac{\overset{(ml)}{24.3} \text{ x } .1 \text{ x } 1{,}000}{(ml)}$$

$$= 24.3 \text{ x } .1 \text{ x } 1{,}000$$

$$= 2.43 \text{ x } 1{,}000$$

$$= 2{,}430 \text{ mg/l}$$